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Signs of intelligence in cross-fostered chimpanzees

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In cross-fostering, the young of one species are reared by adults of another, as in the classical ethological studies of imprinting and song-learning. In our laboratory, infant chimpanzees were reared under human conditions that included two-way communication in American Sign Language (A.S.L.), the gestural language of the deaf in North America. A large body of evidence from five chimpanzees demonstrated stage by stage replication of basic aspects of the acquisition of speech and signs by hearing and deaf children. Here we review evidence that, under double-blind conditions: (i) the chimpanzees communicated information in A.S.L. to human observers; (ii) independent human observers agreed in their identification of the chimpanzee signs, (iii) the chimpanzees could use the signs to refer to natural language categories: DOG for any dog, FLOWER for any flower, SHOE for any shoe.

On 21 June, 1966, an infant chimpanzee arrived in our laboratory. We named her Washoe, for Washoe County, the home of the University of Nevada. To a casual observer Washoe's new home may not have looked very much like a laboratory. In fact, it was the Gardner residence in the suburbs of Reno, purchased as a faculty home some years earlier, a small, one storey, brick and wood home with an attached garage and a largish back yard. To that same casual observer, Washoe's daily life may not have looked much like laboratory routine, either. It was rather more like the daily life of human children of her age in the same suburban neighbourhood.

Washoe was about ten months old when she arrived in Reno, and almost as helpless as a human child of the same age. In the next few years she learned to drink from a cup and eat at a table with forks and spoons. She also learned to set and clear the table and even to wash the dishes, in a childish way. She learned to dress and undress herself and she learned to use the toilet to the point where she seemed embarrassed when she could not find a toilet on an outing in the woods, eventually using a discarded coffee pot that she found on a hike. She had the usual children's toys and was particularly fond of dolls, kissing them, feeding them, and even bathing them. She was interested in picture-books and magazines almost from the first day and she would look through them by herself or with a friend who would name and explain the pictures and tell stories about them. The objects and activities that most attracted her were those that most engaged the grown-ups. She seemed to be fascinated by household tools, eventually acquiring a creditable level of skill with hammers and screwdrivers.

Washoe lived in a second-hand housetrailer, parked in a garden behind the house. With a few minor alterations, it was the same trailer that its previous owners had used as a travelling home. It had the same living-room and bedroom furniture and the same kitchen and toilet facilities. Someone came in to the trailer to check her each night and all through the night, every night, someone listened to her by means of an intercom connected to the Gardner home.

To a casual observer the greatest departure from the world of most human children would probably have been the silence. Modern man is a noisy member of the animal kingdom. Old or young, male or female, wherever you find two or more human beings they are usually vocalizing. By contrast, chimpanzees are usually silent. They seldom vocalize unless they are excited (Yerkes & Yerkes 1929, pp. 301–309; Goodall 1965). Washoe was also very silent and so were her human companions. The only language that we used in her presence was American Sign Language (A.S.L.). There were occasional lapses, as when outside workmen or her paediatrician entered the laboratory, but the lapses were brief and rare.

When Washoe was present, all business, all casual conversation was in A.S.L. Everyone in Washoe's foster family had to be fluent enough to make themselves understood under the sometimes hectic conditions of life with this lively youngster. Visits from non-signers were strictly limited. Some university professors declined to enter the laboratory when they realized that speaking was against the rules. Others discovered within minutes that the discipline was too much for them, 'I know I musn't talk, but...' and their visits were shortened accordingly. A few truly social beings invented their own sign language on the spot. Eventually, we hit on the procedure of teaching visitors a few key phrases that they could repeat indefinitely, I VERY HAPPY MEET YOU, YOU PRETTY GIRL, WASHOE SMART GIRL, and so forth. Visitors from the deaf community who were fluent in A.S.L. were always a welcome relief.

The rule of sign-language-only required some of the isolation of a field expedition. We lived and worked with Washoe on that corner of suburban Reno as if at a lonely outpost in a hostile country. We were always avoiding people who might speak to Washoe. On outings in the country, we were as stealthy and cautious as Indian scouts. On drives in town, we wove through traffic like undercover agents. We could stop at a Dairy Queen or a MacDonald's fast-food restaurant, but only if they had a secluded car park in the back. Then one of Washoe's companions could buy the treats while another waited with her in the car. If Washoe was spotted, the car drove off to return later for the missing passenger and the treats, when the coast was clear.

1. Cross-fostering

The first scientist to comment on the Reno laboratory was Winthrop Kellogg, the great pioneer in this field.

> 'Apes as household pets are not uncommon and several books by lay authors attest to the problems involved.... But pet behavior is not child behavior, and pet treatment is not child treatment. It is quite another story, therefore, for trained and qualified psychobiologists to observe and measure the reactions of a home-raised pongid amid controlled experimental home surroundings. Such research is difficult, confining, and time-consuming. ...Although often misunderstood, the scientific rationale for rearing an anthropoid ape in a human household is to find out just how far the ape can go in absorbing the civilizing influences of the environment. To what degree is it capable of responding like a child and to what degree will genetic factors limit its development?' (Kellogg 1968, p. 423).

Earlier, the Kelloggs had outlined the requirements for cross-fostering.

> 'One important consideration upon which we would insist was that the psychological as well as the physical features of the environment be entirely of a human character. That

is, the reactions of all those who came in contact with the subject, and the resulting stimulation which these reactions afforded the subject, should be without exception just such as a normal child might receive. Instances of anthropoid apes which have lived in human households are of course by no means unknown. But in all the cases of which we have any knowledge the 'human' treatment accorded the animals was definitely limited by the attitude of the owner and by the degree of his willingness to be put to boundless labor. It is not unreasonable to suppose, if an organism of this kind is kept in a cage for a part of each day or night, if it is led about by means of a collar and a chain, or if it is fed from a plate upon the floor, that these things must surely develop responses which are different from those of a human. A child itself, if similarly treated, would most certainly acquire some genuinely unchildlike reactions. Again, if the organism is talked to and called like a dog or a cat, if it is consistently petted or scratched behind the ears as these animals are often treated, or if in other ways it is given pet stimuli instead of child stimuli, the resulting behavior may be expected to show the effects of such stimulation.

'In this connection it was our earnest purpose to make the training of the ape what might be called incidental as opposed to systematic or controlled training. What it got from its surroundings it was to pick up by itself just as a growing child acquires new modes of behavior. We wished to avoid deliberately teaching the animal, trial by trial, a series of tricks or stunts which it might go through upon signal or command. The things that it learned were to be its own reactions to the stimuli about it. They were furthermore to be specifically responses to the household situation and not trained-in or meaningless rituals elicited by a sign from a keeper. The spoon-eating training, to take a concrete example, was to be taken up only in a gradual and irregular manner at mealtime, as the subject's muscular coordination fitted it for this sort of manipulation. We would make no attempt to set it down at specified intervals and labor mechanically through a stated number of trials, rewarding or punishing the animal as it might succeed or fail. Such a proposed procedure, it will be readily seen, is loose and uncontrolled in that it precludes the obtaining of quantitative data on the number of trials necessary to learn, the number of errors made, or the elapsed time per trial. It has the advantage, nevertheless, of being the same sort of training to which the human infant is customarily subjected in the normal course of its upbringing' (Kellogg & Kellogg 1933, pp. 12–13).

It seems as if no form of behaviour is so fundamental or so distinctively species-specific that it is not deeply sensitive to the effects of early experience. Ducklings, goslings, lambs, and many other young animals learn to follow the first moving object that they see, whether it is their own mother, a female of another species, or a shoebox. The mating calls of many birds are so species-specific that an ornithologist can identify them by their calls alone without seeing a single feather. Distinctive and species-specific as these calls may be, they, too, depend upon early experience.

Niko Tinbergen and his students have made the British Herring Gull one of the most thoroughly studied of all animals. Normally reared Herring Gulls spend the entire year in Britain; they never migrate south for the winter. The lesser Black-backed Gull also breeds on British shores, but members of their species normally migrate south to the sea-coasts of Spain, Portugal, and northwest Africa. Harris (1970) arranged for experimental cross-fostering by placing Herring Gull eggs in the nests of lesser Black-backed Gulls and *vice versa*, banding the chicks after hatching so that they could be identified as adults. Many cross-fostered Herring Gulls were recovered on the coasts of Spain and Portugal, even though the effects of cross-fostering failed to induce many lesser Black-backed Gulls to overwinter in Britain.

How about our species, how much does our common humanity depend upon our common experience of a species-typical human childhood? The question is so tantalizing that even alleged but unverified cases of human cross-fostering, such as Itard's account of Victor, 'the wild boy of Aveyron', attract serious scholarly attention. Many, presumably insurmountable, ethical and practical difficulties stand in the way of experimentally controlled, or even verifiable cases of human children cross-fostered by non-human beings. The Kelloggs were the first to attempt the logical alternative; a form of cross-fostering in which the subjects are chimpanzees and the foster parents are human beings.

2. Introduction of A.S.L.

Before Project Washoe, there were, altogether, four professional research projects that had followed Kellogg's procedures of cross-fostering (see Kellogg 1968). In all four cases, the infant chimpanzees thrived, and all aspects of their behavioural development resembled the development of human children, with one striking exception. There was hardly any development of spoken language. In the most successful case, the chimpanzee Viki spoke only four words, MAMA, PAPA, CUP and UP, after nearly seven years of intensive exposure to English together with additional sophisticated, thorough, and ingenious teaching (Hayes & Nissen 1971).

For decades, the failures of Gua and Viki to learn to speak were cited and recited to support the traditional doctrine of absolute, unbridgeable discontinuity between human and non-human. Other scientists, aware of the silent habits of chimpanzees, looked for a technique that would not require speech. This was the innovation of Project Washoe. For the first time, the foster family used a gestural rather than a vocal language.

With the introduction of A.S.L., the line of research pioneered by the Kelloggs and the Hayeses moved forward, dramatically. In 51 months, Washoe acquired at least 132 signs of A.S.L. and used them for classes of referents rather than specific exemplars. Thus, DOG was used to refer to live dogs and pictures of dogs of many breeds, sizes, and colours, as well as the sound of barking by an unseen dog. OPEN was used to ask for the opening of doors to houses, rooms, cupboards, or the lids of jars, boxes, bottles, and even (an invention of Washoe's) for turning on a water tap. Washoe also understood many more signs than she used herself (Gardner & Gardner 1975).

She signed to friends and to strangers. She signed to herself and to dogs, cats, toys, tools, even to the trees. She asked for goods and services, and she also asked questions about the world of objects and events around her. When Washoe had about eight signs in her expressive vocabulary, she began to combine them into meaningful phrases. YOU ME HIDE, and YOU ME GO OUT HURRY were common. She called her doll, BABY MINE; the sound of a barking dog, LISTEN DOG; the refrigerator, OPEN EAT DRINK; and her potty-chair, DIRTY GOOD. Along with her skill with cups and spoons, and pencils and crayons, her signing developed stage for stage much like the speaking and signing of human children (Gardner & Gardner 1971, 1974*a*; Van Cantfort & Rimpau 1982).

Project Washoe was followed by a second, more advanced, venture in cross-fostering

(Gardner & Gardner 1978, 1980). Washoe herself was captured wild in Africa and arrived in Reno when she was about 10 months old. Moja, Pili, Tatu, and Dar, were born in American laboratories and each arrived within a few days of birth. In general, the human participants in the second project had a higher level of expertise in A.S.L. and chimpanzee psychology because some of them were veterans of Project Washoe. Many of the new recruits were deaf or the hearing offspring of deaf parents or had other extensive experience with A.S.L. before they joined the staff. All had learned A.S.L. and studied the procedures and results of Project Washoe beforehand. And, while Washoe was the only chimpanzee in Reno, the foster chimpanzees of the second project had each other as frequent companions. The chimpanzees used the signs of A.S.L. with each other and they learned new signs from each other. At a later stage in the Fouts laboratory, the infant Loulis acquired, and used appropriately, at least 47 signs that he could only have learned from Washoe, Moja, Tatu, or Dar (Fouts *et al.* 1984).

Most commentators have acknowledged that this line of research has demonstrated a significant degree of intellectual continuity between cross-fostered chimpanzees and human children (cf. Bronowski & Bellugi 1970; Brown 1970; Dingwall 1979; Donahoe & Wessells 1980; Griffin 1976; Hewes 1973; Hill 1978; Hockett 1978; Kellogg 1969; Lieberman 1984; Marler 1969; Stokoe 1978; Thorpe 1972; Van Cantfort & Rimpau 1982; Watt 1974). Even among those who remain faithful to the doctrine of ultimate cognitive discontinuity, most have conceded that there is now more evidence of continuity than they would have expected.

Teaching

The development of verbal behaviour, as we know it in the human case, is inextricably bound up in the rest of the conditions of a human childhood. We doubt whether anything comparable could develop under other conditions. It seems equally unlikely that the other aspects of human intellectual growth could flourish without the development of verbal behaviour. Thus, the purpose of A.S.L. in the young lives of Washoe, Moja, Pili, Tatu, and Dar, was to satisfy the requirements of cross-fostering. It was a means, rather than an end in itself. Without two-way communication in a naturally occurring human language, Kellogg's objectives could not be met. The conditions of enhancement would have to fall far short of a human childhood. At the same time, almost any measurement of the intellectual development of human children must soon include verbal behaviour; comparisons between the young chimpanzees and the young children had to include verbal behaviour.

By contrast, much of the other research that followed in the wake of Project Washoe (for example, Premack 1971; Rumbaugh *et al.* 1973; Terrace *et al.* 1979), has assumed discontinuity between verbal behaviour and the rest of intelligent behaviour. By and large, these investigators have sought to separate language from the rest of behaviour by dint of rigorous theoretical analysis and to train their chimpanzee subjects to perform certain narrowly defined tasks based on *a priori* definitions of language. No comparisons have been made with human children performing the same tasks under the same conditions, indeed, no such comparisons are possible.

At the height of the, so called. 'Chomskian revolution' in psycholinguistics, it was frequently claimed that human children acquire their first language with incredible speed by the innate unfolding of a uniquely human mental process, and more or less independently of adult input (Lenneberg 1967, p. 137; McNeill 1966; Moore 1973, p. 4). Needless to say, this claim was always in conflict with common experience. More recently, a large body of painstaking research has supported the more traditional view, that human parents teach their children. As Snow (1977) puts it

'the first descriptions of mothers' speech to young children were undertaken in the late sixties in order to refute the prevailing view that language acquisition was largely innate and occurred almost independently of the language environment. The results of those mothers' speech studies may have contributed to the widespread abandonment of this hypothesis about language acquisition, but a general shift from syntactic to semantic–cognitive aspects of language acquisition would probably have caused it to lose its central place as a tenet of research in any case. [p. 31] ...all language-learning children have access to this simplified speech register. No one has to learn to talk from a confused, error-ridden garble of opaque structure. Many of the characteristics of mothers' speech have been seen as ways of making grammatical structure transparent, and others have been seen as attention-getters and probes to the effectiveness of the communication' [p. 38].

In teaching sign language to Washoe, Moja, Pili, Tatu, and Dar we observed human parents with young children and we imitated them. There was constant chatter about the everday events and objects that might interest the young chimpanzees. Many of the comments were aimed at teaching vocabulary, for example, THAT CHAIR, SEE PRETTY BIRD, MY HAT. Many events and objects were introduced, just so we could sign about them. There were frequent questions to see what was getting across, and we tried hard to answer all the youngsters' questions. By expanding on fragmentary utterances we could use the fragments to teach and to probe. We also followed the parents of deaf children in using an especially simple and repetitious register of A.S.L. and making signs on the youngsters' bodies to capture their attention (cf. Schlesinger & Meadow 1972).

Recording

While teaching was spontaneous and informal, as in a human nursery, the methods of recording results were precisely defined and meticulously followed. Each sign had to meet detailed criteria of form and usage before it was listed as a reliable item of vocabulary. In terms of form it had to correspond to a sign made by human adults, or to an immature variant. Decisions were guided by the judgement of fluent signers who were also familiar with signing in young children. In the case of usage, spontaneity was defined in terms of informative prompting. If the sign was produced by the chimpanzee subject without informative prompting, such as direct modelling or guidance that would induce any portion of the target sign, then it was judged to be spontaneous. To be appropriate, however, it had to be prompted by the verbal and situational context, and the presence of a suitable addressee (Gardner & Gardner 1971, 1975, 1978, 1980).

Appropriate usage was judged on the basis of context notes, with the understanding that infant usage can be either more narrow or more broad than adult usage. Nevertheless, the chimpanzee usage had to have some major overlap with adult usage. Thus, Washoe and Tatu used OUT both for leaving and for entering their quarters in these early records (it was only later that they divided this referential domain between OUT and IN). To refer to signs here and elsewhere throughout our writing, we have used as a gloss, the nearest English equivalent to the sign. This is always a single English word, and it is the gloss listed for that particular sign in one of three references (Fant 1977; Stokoe *et al.* 1976; Watson 1973).

3. Structure and function

Until recently, studies of the development of verbal behaviour in human children concentrated on the acquisition of grammar to the near exclusion of vocabulary. The bulk of the evidence has been based on naturalistic methods such as diary records, inventories of phrases, and samples of utterances. The same naturalistic methods were used with Washoe, Moja, Pili, Tatu, and Dar and comparisons can be found in Gardner & Gardner (1969, 1971, 1974*a*, 1975, 1978, 1980) and in work still in progress. With respect to structure, when Van Cantfort & Rimpau (1982) reviewed the evidence in detail they found that, when the same rules of evidence are applied to both sets of data, the same results are found for the early utterances of children and chimpanzees. As Van Cantfort & Rimpau also showed, arguments for discontinuity that seem to be based on the same data have, instead, been based on a double-standard of evidence. 'Too often the comparisons that are cited are between three-year-old chimpanzees and university-level human beings or between observations of chimpanzee utterances and idealized, theoretical conceptions of human linguistic competence' (p. 65).

Although concern with grammar has occupied so much of the efforts of developmental psycholinguists, in our view it would be a mistake for psychobiologists to neglect method and theory in the study of reference. For, if the development of human verbal behaviour requires any significant expenditure of biological resources, then it must confer selective advantages on its possessors. To confer any selective advantage, however, a biological trait must operate on the world in some way; it must be instrumental in obtaining benefit or avoiding harm. If clarifying one's ideas confers selective advantage it must be because, in some way, clarified ideas provide superior means for operating in the biological world. As for establishing social relations, a system of displays and cries is sufficient to maintain group cohesiveness in most animals. The selective advantage of a wider variety of signals would seem to be the communication of more information. But, unless verbal behaviour refers to objects and events in the external world, it cannot communicate information and it cannot have any such selective advantage. From this point of view, reference is the Darwinian function of verbal behaviour, and the function of grammar or structure in verbal behaviour must be to enlarge the scope and increase the precision of reference.

4. A test of communication†

When Washoe was 27 months old she made a hole in the then flimsy inner wall of her house trailer. The hole was located high up in the wall at the foot in her bed. Before we repaired the hole she managed to lose a toy in the hollow space between the inner and outer walls. When Allen Gardner arrived that evening she attracted his attention to an area of the wall down below the hole at the level of her bed, signing OPEN OPEN many times over that area. It was not hard for Allen Gardner to understand what the trouble was and eventually to fish out the toy. When the toy was found, it was exciting to realize that a chimpanzee has used a human

† See Gardner & Gardner (1984) for a complete description of the procedure and results of these tests.

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language to communicate truly new information. It was not long before such situations became commonplace. For example, Washoe's playground was in the garden behind a single-storey house. High in her favourite tree, Washoe was often the first to know who had arrived at the front of the house and her companions on the ground learned to rely on her to tell them who was arriving and departing.

Washoe could tell her human companions things that they did not already know. This is what Clever Hans could not do. Clever Hans, it will be remembered, was a German horse that seemed to do arithmetic by tapping out numbers with his hoof. Not the circus trainers nor the cavalry officers, not the veterinarians nor the zoo directors, not even the philosophers and the linguists who studied the case could explain how Clever Hans did it. Nevertheless an experimental psychologist, Oskar Pfungst (1911), unravelled the problem with the following test. Pfungst whispered one number into Clever Hans left ear and Herr von Ost, the trainer, whispered a second number into the horse's right ear. When Clever Hans was the only one who knew the answer, he could not tap out the correct sums. He could not tell his human companions anything that they did not already know.

Since then, controls for 'Clever Hans errors' have been standard procedure in comparative psychology†. To date most, if not all, research on human children has been carried out without any such controls. It is as if students of child development believed that, whereas horses and chimpanzees may be sensitive to subtle non-verbal communication, it is safe to assume that human children are totally unaffected.

Method

Early in Project Washoe we devised vocabulary tests to demonstrate that chimpanzees could use the signs of A.S.L. to communicate information. The earliest versions are described in Gardner & Gardner (1971), pp. 158–161, 1974*a*, pp. 11–15, 1974*b*, pp. 160–161). The first objective of these tests was to demonstrate that the chimpanzee subjects could communicate information under conditions in which the only source of information available to a human observer was the signing of the chimpanzees. To accomplish this, nameable objects were photographed on 35 mm slides. During testing, the slides were back-projected on a screen that could be seen by the chimpanzee subject, but could not be seen by the observer. The slides were projected in a random order that was changed from test to test so that the order could not be memorized either by the observer or by the subject.

The second objective of these tests was to demonstrate that independent observers agreed with each other. To accomplish this, there were two observers. The first observer (O_1) served as interlocutor in the testing room with the chimpanzee subject. The second observer (O_2), was stationed in a second room and observed the subject from behind one-way glass, but could not see the projection screen. The two observers gave independent readings; they could not see each other and they could not compare observations until after a test was completed.

The third objective of these tests was to demonstrate that the chimpanzees used the signs to refer to natural language categories: that the sign DOG could refer to any dog, FLOWER to any flower, SHOE to any shoe, and so on (Rosch & Lloyd 1978; Saltz *et al.* 1972, 1977). This was accomplished by preparing a large library of slides to serve as exemplars. Some of the slides

† In modern times a striking exception to this rule has been the work of Terrace (1979) with the chimpanzee Nim, which included no controls whatever for 'Clever Hans errors'.

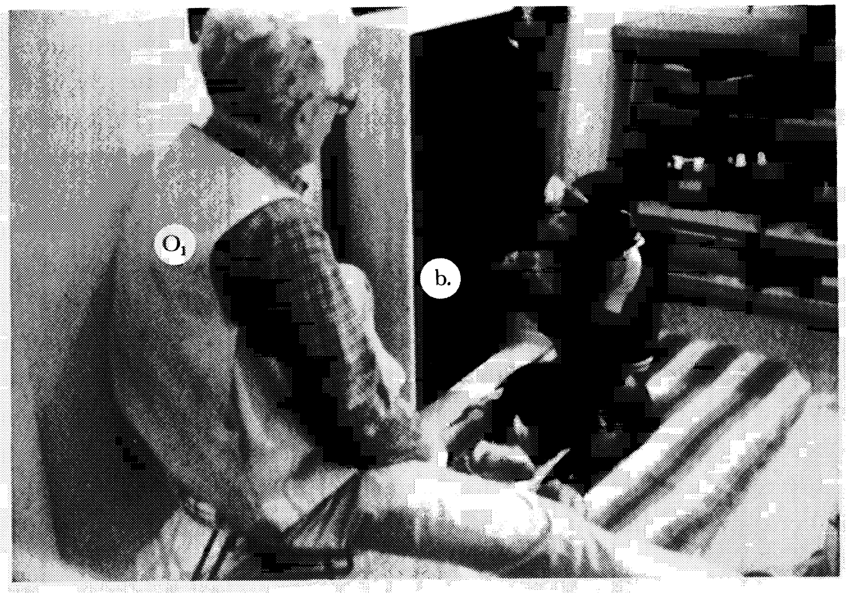

FIGURE 1. Room 1 of the vocabulary testing apparatus used with Moja, Tatu, and Dar. Chimpanzee Dar sits in front of the projection screen, which is recessed within the cabinet. O_1, seated beside the cabinet, can see Dar's signs but cannot see the projecton screen. By pressing the white push-button (b.), Dar makes a picture appear on the screen. (The vocabulary testing apparatus used with Washoe was slightly different; see Gardner & Gardner, 1974*a*, pp. 11–16).

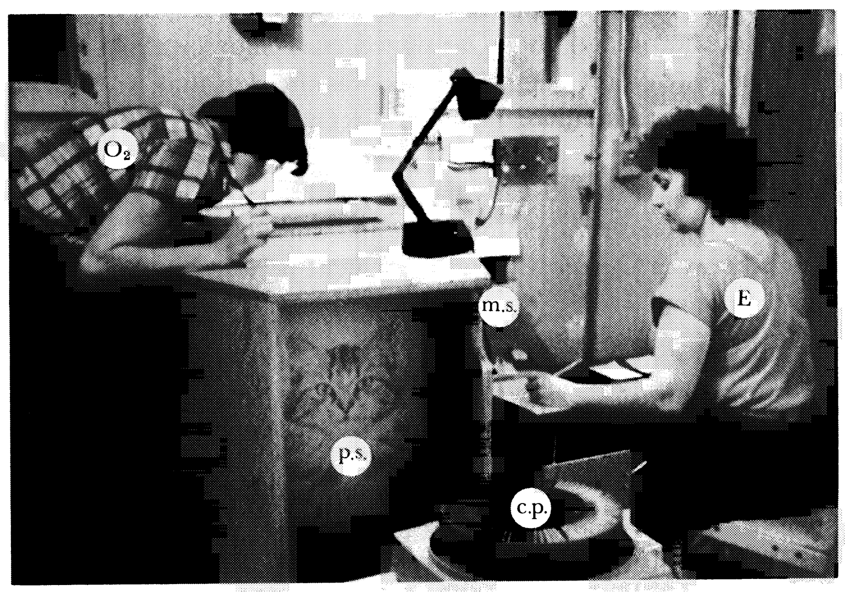

FIGURE 2. Room 2: a carousel projector (c.p.) shows the slides. Standing to one side of the cabinet, O_2 can see the subject through the one-way glass window but cannot see the projection screen (p.s.). O_2 writes down what the subject signs and passes the message slip to the experimenter (E), who also receives written messages from O_1, via the message slot (m.s.). After receiving a message slip from O_1 and O_2, E. steps the carousel to the slide for the next trial.

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were used in pre-tests that served to adapt subjects, observers, and experimenters to the testing procedure. The slides that were reserved for the tests were never shown during pre-tests so that the first time that a particular chimpanzee subject saw any one of the test slides was on a test trial and no test slide was shown on more than one test trial. Consequently, there was no way that a subject could get a correct score by memorizing particular pairs of exemplars and signs. That is to say, scores on these tests depended upon the ability to name new exemplars of natural language categories.

The vocabulary items that appeared in Moja's single test and in the second test of each of the other three subjects are listed in table 1. All of the vocabulary items tested in this way had to be names of picturable objects (see Gardner & Gardner 1984). Differences among the subjects in table 1 reflect differences in their vocabularies as well as a strategy of overlapping tests that would sample the range of picturable objects in the vocabularies without making the tests excessively long. For each test we chose four exemplars of each vocabulary item to illustrate the range of objects that a subject could name with the same sign. Different breeds represented CAT and DOG, different species repesented BIRD and BUG, different makes and models represented CAR. The number of vocabularly items and the resulting number of trials (items × exemplars) appear in table 2.

The correct sign for each vocabulary item was designated in advance of the tests. That sign and that sign only was scored as correct for that item. Although there were aspects of the pictures for which superordinate terms, such as FOOD, or descriptive terms such as BLACK, might be scored, neither the presence or absence nor the correct or incorrect use of such terms was considered in the scoring of these tests.

Most of the replies consisted of a single sign which was the name of an object. Sometimes, the single noun in the reply was contained in a descriptive phrase, as when Tatu signed RED BERRY for a picture of cherries, or when Dar signed THAT BIRD for a picture of a duck. These replies contained only one object name and that was the sign that was scored as correct or incorrect. Occasionally, there was more than one object name in a reply, as when Washoe signed FLOWER TREE LEAF FLOWER for a picture of a bunch of daisies. In such cases, the observers designated a single sign for scoring (usually the first) without looking at the picture themselves. For each trial and each observer, then, one sign and one sign only, in each report was used to score agreement between O_1 and O_2 and agreement between the reports of the observers and the name of the exemplar.

Results

Table 2 shows how the major objectives of the tests were accomplished. The agreement between O_1 and O_2 was high for all seven tests; except for Moja, the agreement ranged between 86% and 95%. Note that this is the agreement for both correct and incorrect signs. The agreement between the signs reported by O_1 and O_2 and the correct names of the categories is also high; except for Moja, correct scores ranged between 71% and 88%.

The line labelled 'expected' in table 2 needs some explanation. When we first described this testing procedure (Gardner & Gardner 1971) we estimated the expected chance performance as $1/N$ where N is the number of vocabulary items on a test and all items are represented by the same number of exemplars. This estimate was based on the assumption that only the chimpanzees were guessing and that their guessing strategies could only be randomly related to the random sequence of presentation. But, this estimate may be too low because it does not

Table 1. Vocabulary items in the tests of four chimpanzees

items	chimpanzees				items	chimpanzees			
animates	W	M	T	D	foods	W	M	T	D
BABY	+	.	+	+	APPLE	.	+	+	+
BIRD	+	+	+	+	BANANA	.	+	+	+
BUG	+	+	+	+	BERRY	.	+	+	+
CAT	+	+	+	+	CARROT	.	.	+	+
COW	+	+	+	+	CEREAL	.	+	.	.
DOG	+	+	+	+	CHEESE	+	.	+	+
HORSE	.	+	.	.	CORN	.	+	+	+
					FRUIT	+	.	.	.
plants					GRAPES	.	+	.	.
FLOWER	+	+	+	+	GUM	.	+	.	.
LEAF	+	+	.	.	ICE CREAM	.	+	+	+
TREE	+	+	+	+	MEAT	+	.	+	+
					NUT	+	+	+	+
clothing					ONION	.	+	.	.
CLOTHES	+	.	.	.	ORANGE	.	+	.	.
HAT	+	+	+	+	PEA–BEAN	.	+	.	.
PANTS	+	.	.	.	PEACH	.	+	+	+
SHOE	+	+	+	+	SANDWICH	.	.	+	+
					TOMATO	+	.	.	.
grooming									
BRUSH	+	+	+	.	drinks				
COMB	.	+	+	.	COFFEE	.	.	+	+
HANKIE	.	.	+	.	DRINK	+	.	.	.
LIPSTICK	.	.	+	.	MILK	.	+	.	.
OIL	+	.	+	+	SODAPOP	.	+	+	+
TOOTHBRUSH	+	+	+	+					
WIPER	+	.	.	.	other				
					BALL	.	.	+	+
sensory					BOOK	+	+	.	.
LISTENS	+	+	.	.	CAR	+	.	+	+
LOOKS	+	+	+	.	HAMMER	+	.	.	.
SMELLS	+	.	.	.	KEY	+	+	+	.
					KNIFE	.	+	.	.
					PEEKABOO	.	.	+	.
					PIPE	+	.	.	.
					SMOKE	+	+	.	.

take into account the possibility that the observers were guessing. In random sampling without replacement, the probabilities of later events in a sequence depend on earlier events. The observers could have used their knowledge of the items that had appeared earlier to predict the items that would appear later. Thus, players who can remember the cards that have already been played can win significant amounts at games such as blackjack. Diaconis (1978) and Read (1962) deal with a similar problem in demonstrations of extra-sensory perception (e.s.p.). When highly motivated subjects in e.s.p. experiments can see each target card after each prediction, their later predictions tend to improve.

To estimate the effect of informed guessing by the observers on chance expectancy in the tests reported here, James C. Patterson (1983) performed a computer simulation which assumes that both observers; (i) saw each slide after each trial; (ii) had perfect memory for the number of exemplars of each vocabulary item that had appeared before the beginning of each trial; and (iii) guessed the correct sign on the basis of the number of exemplars of each vocabulary

TABLE 2. SCORES ON THE VOCABULARY TESTS OF FOUR CHIMPANZEES

chimpanzee subject	Washoe		Moja	Tatu		Dar	
test	1	2	1	1	2	1	2
vocabulary items	16	32	35	25	34	21	27
trials	64	128	140	100	136	84	108
inter-observer agreement (%)	95	86	70‡	89	91	90	94
scored correct by							
observer 1 (%)	86	72	54§	84	80	79	83
observer 2 (%)	88	71	54§	85	79	80	81
expected† (%)	15	4	4	6	4	6	5

† Assuming that the observer was guessing on the basis of perfect memory for all previous trials that that observer had seen.

‡ Based on 135 trials; O_2 missed five trials.

§ Based on 132 trials; eight unscorable trials.

item that remained to be presented. The expected scores in table 2 are the average results of 2000 simulated runs for each of the seven tests. In all cases, this estimate is a small fraction of the obtained scores. Since, O_1 and O_2 reported extra-list intrusions (signs that were not on the target lists) they were using a less efficient strategy than that assumed in Patterson's simulation. Hence, small as they are, the values in the expected line of table 2 over-estimate chance expectancy.

The expected score for Washoe's first test is appreciably higher than the expected scores for the other six tests for two reasons. First, this test was shorter than the other tests and predictability depends on the number of vocabulary items: the fewer the items the greater the predictability. Second, and more significantly for this discussion, predictability increases as we approach the end of the test. The last trial is completely predictable, since there is only one vocabulary item that could have any remaining exemplars. The next to the last trial may be completely predictable, but there are at most two vocabulary items that could still appear, and so on. In all cases, except for Washoe's first test, both O_1 and O_2 were assigned to test sessions in such a way that no individual served as an observer for more than half of the trials of any single test. The device is similar to the way gambling casinos can defeat card-counting customers by reshuffling the deck. The smaller number of items and the assignment of the same two observers to both sessions of Washoe's first test account for the higher, but still quite small, expected score on that test.

Concepts

To make sure that the signs referred to conceptual categories, all of the test trials were first trials; that is, each slide was shown to the subject for the first time on the one and only test trial in which it was presented to that subject. All of the specific stimulus values varied, as they do in natural language categories: that is to say, most human beings would agree that the exemplars in each set belong together. Apparently, Washoe, Moja, Tatu, and Dar agreed with this assignment of exemplars to conceptual categories (See Gardner & Gardner 1984, figures 3, 4, 5 and 6).

When teaching a new sign, we usually began with a particular exemplar: a particular toy for BALL, a particular shoe for SHOE. At first, especially with very young subjects, there would be very few balls and very few shoes. The same situation is common in human nursery life. Early in Project Washoe we worried that the signs might become too closely associated with their initial referents. It turned out that this was no more a problem for Washoe or any of our other subjects that it is for children. The chimpanzees easily transferred the signs they had learned for a few balls, shoes, flowers, or cats to the full range of the categories wherever they found them and however represented, as if they divided the world into the same conceptual categories that human beings use.

It is reasonable to suppose that non-human animals use natural language concepts outside the laboratory. A wild monkey that finds a ripe mango in a tree must learn something general about ripe mangoes, because it is certain that that monkey will never get to pick that particular mango again. A young lion that brings down an impala must learn something general about hunting impalas, because it is certain that that lion will never get to hunt that particular impala again. The same must be truc of young hawks hunting field mice. It seems unlikely that any creature with a natural world as complex as that of a wild pigeon could earn its living without using some natural language concepts.

So much experimentation has been limited to precisely repeated stimulus objects or to objects that vary only in simple dimensions, such as colour and size, that it would be easy to form the impression that the conceptual abilities of non-human beings are severely limited. But, there have been notable exceptions. Hayes & Hayes (1953) working with chimpanzee Viki, Hicks (1956) and Sands *et al.* (1982) working with monkeys, and Herrnstein *et al.* (1976) as well as Herrnstein (this symposium) with pigeons, for example, have all demonstrated that non-human beings can use natural language concepts when they are presented with suitably varied stimulus material.

Significant variation among exemplars and testing with true first trials are essential to the definition of natural language categories. More concerned with theoretical definitions of language than with reference, the Rumbaughs (Essock *et al.* 1977; Gill & Rumbaugh 1974; Savage-Rumbaugh *et al.* 1983) have administered hundreds of trials of training and testing with identical exemplars or with minimally varied exemplars. To be sure, the Rumbaughs have concentrated their efforts on the arbitrariness of what they call 'lexigrams' and the use of the 'lexigrams' in arbitrarily fixed sequences. The stated objective has been to satisfy certain theoretical definitions of 'symbolic communication', and such methods may be appropriate for that objective. It seems likely that, given the opportunity, the Rumbaugh chimpanzees could also have used natural language categories.

As for Terrace and his associates (Terrace 1979; Terrace *et al.* 1980) they never attempted any experimental analysis of reference. As a matter of fact their work is unique in this field in that they never administered any systematic tests at all. Since the time of Kellogg & Kellogg (1933), it is the first study in this field that was entirely restricted to adventitious naturalistic observations.

5. Communication and motive

Normal human children learn to speak as if they were born with a powerful motive to communicate; no extrinsic reward seems to be necessary. In modern times, of course, we recognize that there are many inborn motives rather than a few basic ones, such as hunger and thirst that give rise to the rest through a process of conditioning. Moreover, other inborn and unlearned motives, can be more powerful determinants of behaviour than hunger and thirst. Harry Harlow's experiments on contact comfort come immediately to mind (Harlow 1958). It is also clear now that many other species behave as if they were born with a powerful motive to communicate. The need to communicate is by no means uniquely human (Tinbergen

1953). Inborn motives such as contact, comfort and communication have obvious selective advantages. To the modern mind, the existence of many such inborn motives seems rather more compatible with Darwinism than the elaborate process of conditioning based on hunger and thirst that was formerly posited.

Chimpanzees are among the many species that behave as if they were born with a powerful motive to communicate (Van Lawick-Goodall 1968). Captive chimpanzees are similar to wild chimpanzees in this respect (Kellogg 1968) unless their conditions of captivity are so severe that normal behaviour is suppressed. On the basis of our own early observations (Gardner & Gardner 1971, p. 141), and reports of Viki, particularly Hayes & Nissen (1971) (written in 1957 and made available to us in draft form in the early days of Project Washoe) we learned to avoid all forms of drill. In the Reno laboratory, the only time that formal, trial-by-trial procedures were used for teaching A.S.L. (as opposed to testing) was in Fouts' (1972) experiment, a Ph.D. dissertation designed to isolate the effects of two specific procedures, modelling and moulding. Occasionally, we did introduce extrinsic rewards as, for example, when we rewarded Tatu and Dar with treats for obedient test-taking behaviour, but the extrinsic rewards usually had to be discontinued because their main effect was to interfere with the intrinsically motivated task at hand.

The following example taken from Hayes & Nissen (1971) is typical of cross-fostered chimpanzees.

> '...one hot summer day [Viki] brought a magazine illustration of a glass of iced tea to a human friend. Tapping it, she said 'Cup! Cup!' and ran to the refrigerator, pulling him along with her. It occurred to us that pictures might be used to signify needs more explicitly than words...
>
> A set of cards was prepared showing magazine illustrations in natural color of those things she solicited most frequently [for four days Viki consistently used the picture-cards for requests, but on the fifth day]...suddenly she acted as if imposed upon. She had to be coaxed to cooperate and then used the pictures in a completely random way.
>
> [after seven months of erratic performance]...the technique which had seemed so promising was dropped, pending revision. Spring weather, plus a new car, gave Viki a wanderlust so that no matter what situation sent her to the picture-communication pack, when she came upon a car picture she made happy noises and prepared to go for a ride. We eliminated all car pictures from the pack, but it was too late. Long afterwards Viki was tearing pictures of automobiles from magazines and offering them as tickets for rides' (pp. 107–108).

At the same time, experiments with human children (see, for example, Lepper *et al.* 1973; Levine & Fasnacht 1974) have demonstrated that the heavy-handed application of extrinsic rewards impairs performance on intrinsically motivated tasks, such as drawing. Heavy reliance on extrinsic rewards probably has a similar negative effect on the performance of chimpanzees. Characteristically, those who have relied most heavily on extrinsic rewards have been those who most insistently claimed that chimpanzees lack the intrinsic motivation to communicate (Savage-Rumbaugh & Rumbaugh 1978; Savage-Rumbaugh *et al.* 1983, pp. 462, 485–486; Terrace, 1979, pp. 221–224; Terrace *et al.* 1980, pp. 438–440).

Obviously, as their verbal skills improved, Washoe, Moja, Tatu, and Dar were more successful in making their wants known and, presumably, more successful in getting what they wanted. But, certainly the same can be said for human children, or human adults, for that matter. Also, those serving as O_1 often showed their approval or disapproval by smiling or frowning, by nodding or shaking their heads, and by praising the chimpanzees in A.S.L. This was carried over from the cross-fostering régime that was maintained at all times. It is the same way that human adults normally respond to the verbal behaviour of human children.

6. Concluding remarks

In this article we have reviewed a small portion of the published and still to be published record of our sign language studies of chimpanzees. In comparing these cross-fostered chimpanzees with human children, we must consider how very young and immature they were. Chimpanzees begin to lose their milk teeth when they are five or six years old. Under natural conditions in Africa, infants are not weaned until they are four or five years old, they usually live with their mothers until they are seven, and often continue to live with their mothers until they are ten or eleven. The youngest wild chimpanzee mother at the Gombe Stream was twelve years old when her first baby was born (Van Lawick-Goodall 1973). While the life span of wild chimpanzees is still unknown, we do know that captive chimpanzees can remain vigorously and intelligently alive for more than 50 years (Maple & Cone 1981).

Washoe was captured wild in Africa, so we cannot know just when she was born, but dentition and other indicators agree with our estimate of an age of nine to eleven months at the time she arrived in Reno. Washoe was maintained under cross-fostering for only 51 months, Moja only 78 months, Tatu only 65 months, and Dar only 58 months. At that age Moja, the oldest, had only lost six of her milk teeth. It is clear that they were much too young to demonstrate the limits of chimpanzee intelligence and the full benefits of cross-fostering. Moreover, these were the first subjects to be treated with the new technique. Our strongest conclusion is that there is still much more to be discovered about the continuity between verbal and non-verbal and human and non-human.

In the concluding remarks of our first publication on this subject, which covered Washoe's first 22 months of cross-fostering, we wrote,

> 'at an earlier time we would have been more cautious about suggesting that a chimpanzee might be able to produce extended utterances to communicate information. We believe now that it is the writers – who would predict just what it is that no chimpanzee will ever do – who must proceed with caution' (Gardner & Gardner (1969) pp. 671–672).

Bronowski & Bellugi (1970) were the first to publish an article on the limits of chimpanzee intelligence based on that partial report of Washoe's first 22 months in Reno. Each successive report of further progress has generated a fresh wave of commentators, and among the commentators there have always been those who were convinced that at last the final limits were in sight. In those circles, the new evidence has provoked, not caution, but ever more daring hypotheses about the theoretical basis for the newly discovered limits (Terrace *et al.* 1979; Terrace, this symposium).

In 1910, when aviation was probably more advanced than our cognitive sciences are today, two senior engineers, Jackman and Russell wrote in their pioneering book on the construction and operation of flying machines,

> 'in the opinion of competent experts it is idle to look for a commercial future for the flying machine. There is, and always will be, a limit to its carrying capacity which will prohibit its employment for passenger or freight purposes in a wholesale or general way. There are some, of course, who will argue that because a machine will carry two people, another may be constructed that will carry a dozen, but those who make this contention do not understand the theory of weight sustention in the air; or that the greater the load the greater must be the lifting power (motors and plane surface), and that there is a limit to these – as will be explained later on – beyond which the aviator cannot go' (p. 22).

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References

Bronowski, J. & Bellugi, U. 1970 Language, name and concept. *Science, Wash.* **168**, 669–673.
Brown, R. 1970 The first sentences of child and chimpanzee. In *Selected psycholinguistic papers* (ed. R. Brown), pp. 208–281. New York: Macmillan.
Diaconis, P. 1978 Statistical problems in ESP research. *Science, Wash.* **201**, 131–136.
Dingwall, W. O. 1979 The evolution of human communication systems. *Stud. Neuroling.* **4**, 1–95.
Donahoe, J. W. & Wessells, M. G. 1980 *Learning, language, and memory*. New York: Harper & Row Publishers.
Essock, S. M., Gill, T. V. & Rumbaugh, D. M. 1977 Language relevant object- and color-naming tasks. In *Language learning by a chimpanzee* (ed. D. M. Rumbaugh), pp. 193–206. New York: Academic Press.
Fant, L. 1977 *Sign language*. Northridge, California: Joyce Media, Inc.
Fouts, R. S. 1972 Use of guidance in teaching sign language to a chimpanzee. *J. comp. Physiol. Psychol.* **80**, 515–522.
Fouts, R. S., Fouts, D. H. & Schoenfeld, D. 1984 Sign language conversational interaction between chimpanzees. *Sign Lang. Stud.* **42**, 1–12.
Gardner, B. T. & Gardner, R. A. 1971 Two-way communication with an infant chimpanzee. In *Behaviour of nonhuman primates* (ed. A. Schrier and F. Stollnitz), vol. 4, pp. 117–184. New York: Academic Press.
Gardner, B. T. & Gardner, R. A. 1974*a* Comparing the early utterances of child and chimpanzee. In *Minnesota symposium on child psychology* (ed. A. Pick), vol. 8, pp. 3–23. Minneapolis: University of Minnesota Press.
Gardner, B. T. & Gardner, R. A. 1975 Evidence for sentence constituents in the early utterances of child and chimpanzee. *J. exp. Psychol.: General* **104**, 244–267.
Gardner, B. T. & Gardner, R. A. 1980 Two comparative psychologists look at language acquisition. In *Children's language* (ed. K. E. Nelson), vol. 2, pp. 331–369. New York: Gardner Press.
Gardner, R. A. & Gardner B. T. 1969 Teaching sign language to a chimpanzee. *Science, Wash.* **165**, 664–672.
Gardner, R. A. & Gardner, B. T. 1974*b* Teaching sign language to the chimpanzee, Washoe. *Bull. Audio Phonol.*, **4**, 145–173.
Gardner, R. A. & Gardner, B. T. 1978 Comparative psychology and language acquisition. *Ann. N.Y. Acad. Sci.* **309**, 37–76.
Gardner, R. A. & Gardner, B. T. 1984 A vocabulary test for chimpanzees. *J. comp. Psychol.* **98**, 381–404.
Gill, T. V. & Rumbaugh, D. M. 1974 Mastery of naming skills by a chimpanzee. *J. Human Evol.* **3**, 483–492.
Goodall, J. 1965 Chimpanzees of the Gombe Stream Reserve. In *Primate behavior: field studies of monkeys and apes* (ed. I. DeVore), pp. 425–473. New York: Holt, Rinehart & Winston.
Griffin, D. 1976 *The question of animal awareness: evolutionary continuity of mental experience*. New York: The Rockefeller University Press.
Harlow, H. F. 1958 The nature of love. *Am. Psychol.* **13**, 673–685.

Harris, M. P. 1970 Abnormal migration and hybridization of *Larus argentatus* and *L. fuscus* after interspecies fostering experiments. *Ibis* **112**, 488–498.
Hayes, K. J. & Hayes, C. 1953 Picture perception in a home-raised chimpanzee. *J. comp. Physiol. Psychol.* **46**, 470–474.
Hayes, K. J. & Nissen, C. H. 1971 Higher mental functions of a home-raised chimpanzee. In *Behavior of nonhuman primates* (ed. A. M. Schrier & F. Stollnitz), vol. 4, pp. 59–115. New York: Academic Press.
Herrnstein, R. J., Loveland, D. H, & Cable C. 1976 Natural concepts in pigeons. *J. exp. Psychol. Anim. Behav. Proc.* **2**, 285–302.
Hewes, G. W. 1973 Pongid capacity for language acquisition: An evaluation of recent studies. *Symp. Fourth int. Congr. Primatol.* **1**, 124–143.
Hicks, L. H. 1956 An analysis of number-concept formation in the rhesus monkey. *J. comp. Physiol. Psychol.* **49**, 212–218.
Hill, J. 1978 Apes and language, *Ann. Rev. Anthropol.* **7**, 89–112.
Hockett, C. F. 1978 In search of Jove's brow. *Am. Speech* **53**, 243–314.
Jackman, W. J. & Russell, T. H. 1910 *Flying machines: construction and operation.* Chicago: The Charles C. Thompson Co.
Kellogg, W. N. 1968 Communication and language in the home-raised chimpanzee. *Science, Wash.* **162**, 423–427.
Kellogg, W. N. 1969 Research on the home-raised chimpanzee. In *The chimpanzee* (ed. G. H. Bourne), vol. 1, pp. 369–392. Basel: S. Karger.
Kellogg, W. N. & Kellogg, L. A. 1933 *The ape and the child.* New York: Hafner.
Lenneberg, E. 1967 *Biological foundations of language.* New York: John Wiley.
Lepper, M. R., Greene, D. & Nisbett, R. E. 1973 Undermining children's intrinsic interest with extrinsic rewards. *J. Personal. soc. Psychol.* **28**, 129–137.
Levine, F. & Fasnacht, G. 1974 Token rewards may lead to token learning. *Am. Psychol.* **29**, 816–820.
Lieberman, P. 1984 *The biology and evolution of language.* Cambridge, Mass.: Harvard University Press.
Maple, T. L. & Cone, S. G. 1981 Aged apes at the Yerkes Regional Primate Research Center. *Lab. Primate Newsl.* **20**, 10–12.
Marler, P. 1969 Animals and man: communication and its development. In *Communication* (ed. J. D. Roslansky), pp. 25–61. Amsterdam: North-Holland.
McNeill, D. 1966 The creation of language by children. In *Psycholinguistics papers* (ed. J. Lyons and R. Wales), pp. 99–114. Edinburgh: Edinburgh University Press.
Moore, T. E. (ed.) 1973 *Cognitive development and the acquisition of language.* New York: Academic Press.
Patterson, J. C. 1983 Computational formulas for use in card-guessing with information. Paper presented at the Mid-South Colloquium in Mathematical Sciences, Memphis, Tennessee, February 1983.
Pfungst, O. 1911 *Clever Hans* (transl. by C. L. Rahn). New York: Henry Holt.
Premack, D. 1971 Language in chimpanzee? *Science, Wash.* **172**, 808–822.
Read, R. C. 1962 Card-guessing with information – a problem in probability. *Am. math. Monthly* **69**, 506–511.
Rosch, E. & Lloyd, B. B, (eds) 1978 *Cognition and categorization.* Hillsdale, N.J.: Lawrence Erlbaum.
Rumbaugh, D. M., Gill, T. V. & Von Glasersfeld, E. 1973 Reading and sentence completion by a chimpanzee. *Science, Wash.* **182**, 731–733.
Saltz, E., Soller, E. & Sigel, I. 1972 The development of natural language concepts. *Child Devel.* **43**, 1191–1202.
Saltz, E., Dixon, D., Klein, S. & Becker, G. 1977 Studies of natural language concepts. III. Concept overdiscrimination in comprehension between two and four years of age. *Child Devel.* **48**, 1682–1685.
Sands, S. F., Lincoln, C. E. & Wright, A. A. 1982 Pictorial similarity judgements and the organization of visual memory in the rhesus monkey. *J. exp. Psychol.: General* **111**, 369–389.
Savage-Rumbaugh, E. S. & Rumbaugh, D. M. 1978 Symbolization, language, and chimpanzees: A theoretical reevaluation based on initial language acquisition processes in four young *Pan troglodytes. Brain Lang.* **6**, 265–300.
Savage-Rumbaugh, E. S., Pate, J. L., Lawson, J., Smith, S. T. & Rosenbaum, S. 1983 Can a chimpanzee make a statement? *J. exp. Psychol.: General* **112**, 457–492.
Schlesinger, H. S. & Meadow, K. P. 1972 *Deafness and mental health: a developmental approach.* Berkeley: University of California Press.
Snow, C. 1977 Mother's speech research: from input to interaction. In *Talking to children* (ed. C. Snow and C. Ferguson), pp. 31–49. Cambridge: Cambridge University Press.
Stokoe, W. C. 1978 Sign language versus spoken language. *Sign Lang. Stud.* **18**, 69–90.
Stokoe, W. C., Casterline, D. C. & Croneberg, C. G. 1976 *A dictionary of American Sign Language on linguistic principles.* Silver Spring: Linstok Press.
Terrace, H. S. 1979 *Nim.* New York: Knopf.
Terrace, H. S., Pettito, L., Sanders, R. J. & Bever, T. G. 1979 Can an ape create a sentence? *Science, Wash.* **206**, 891–902.
Terrace, H. S., Pettito, L., Sanders, R. J. & Bever, T. G. 1980 On the grammatical capacity of apes. In *Children's language* (ed. K. E. Nelson), vol. 2, pp. 371–495. New York: Gardner Press.
Thorpe, W. H. 1972 The comparison of vocal communication in animal and man. In *Non-verbal communication* (ed. R. A. Hinde), pp. 27–47. Cambridge: Cambridge University Press.

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Tinbergen, N. 1953 *Social behaviour in animals*. New York: John Wiley.

Van Cantfort, T. E. & Rimpau, J. B. 1982 Sign language studies with children and chimpanzees. *Sign Lang. Stud.* **34**, 15–72.

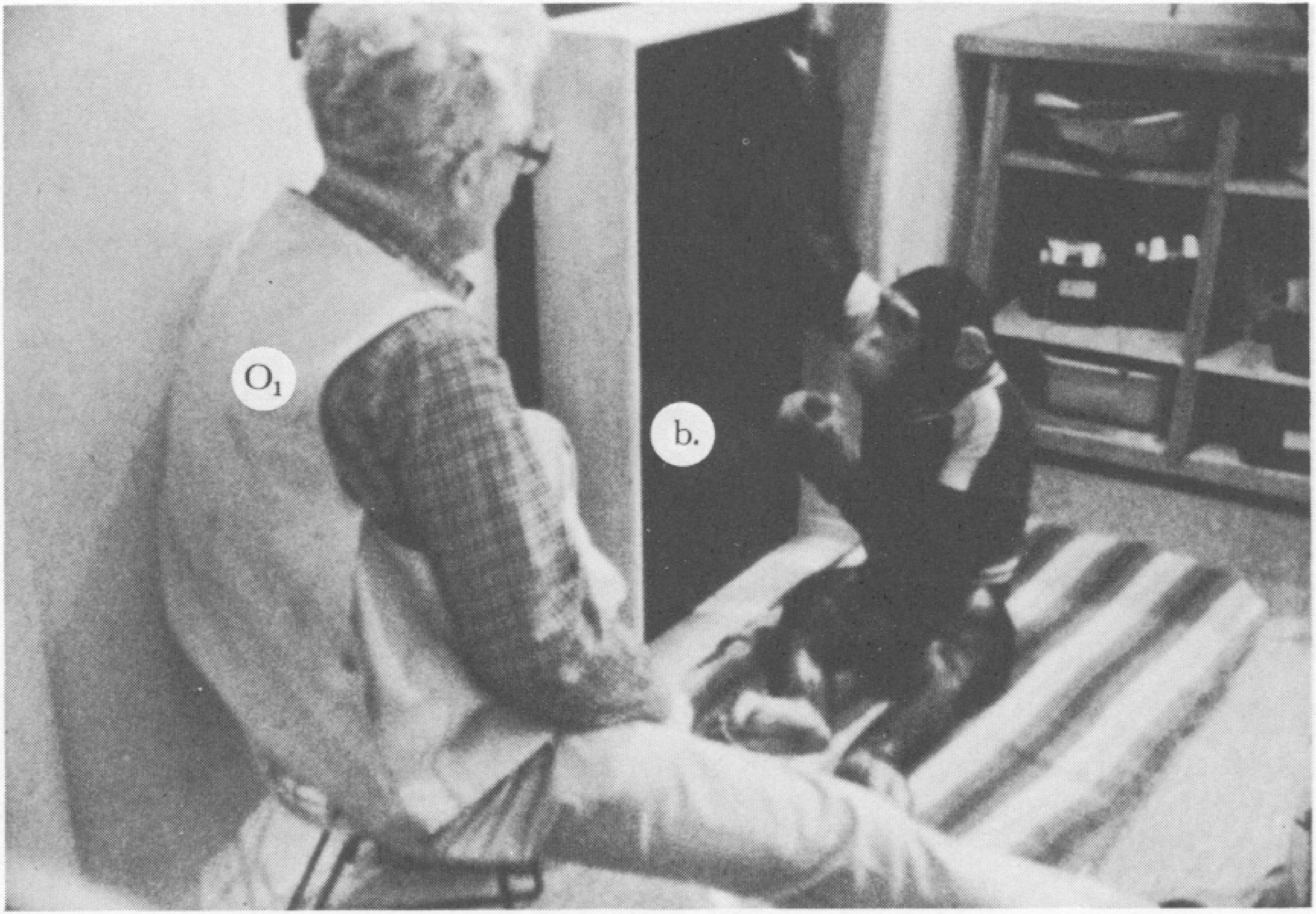
Van Lawick-Goodall, J. 1968 A preliminary report on expressive movements and communication in the Gombe Stream chimpanzees. In *Primates: studies in adaptation and variability* (ed. P. C. Jay), pp. 313–374. New York: Holt, Rinehart and Winston.

Van Lawick-Goodall, J. 1973 The behavior of chimpanzees in their natural habitat. *Am. J. Psychiat.* **130**, 1–11.

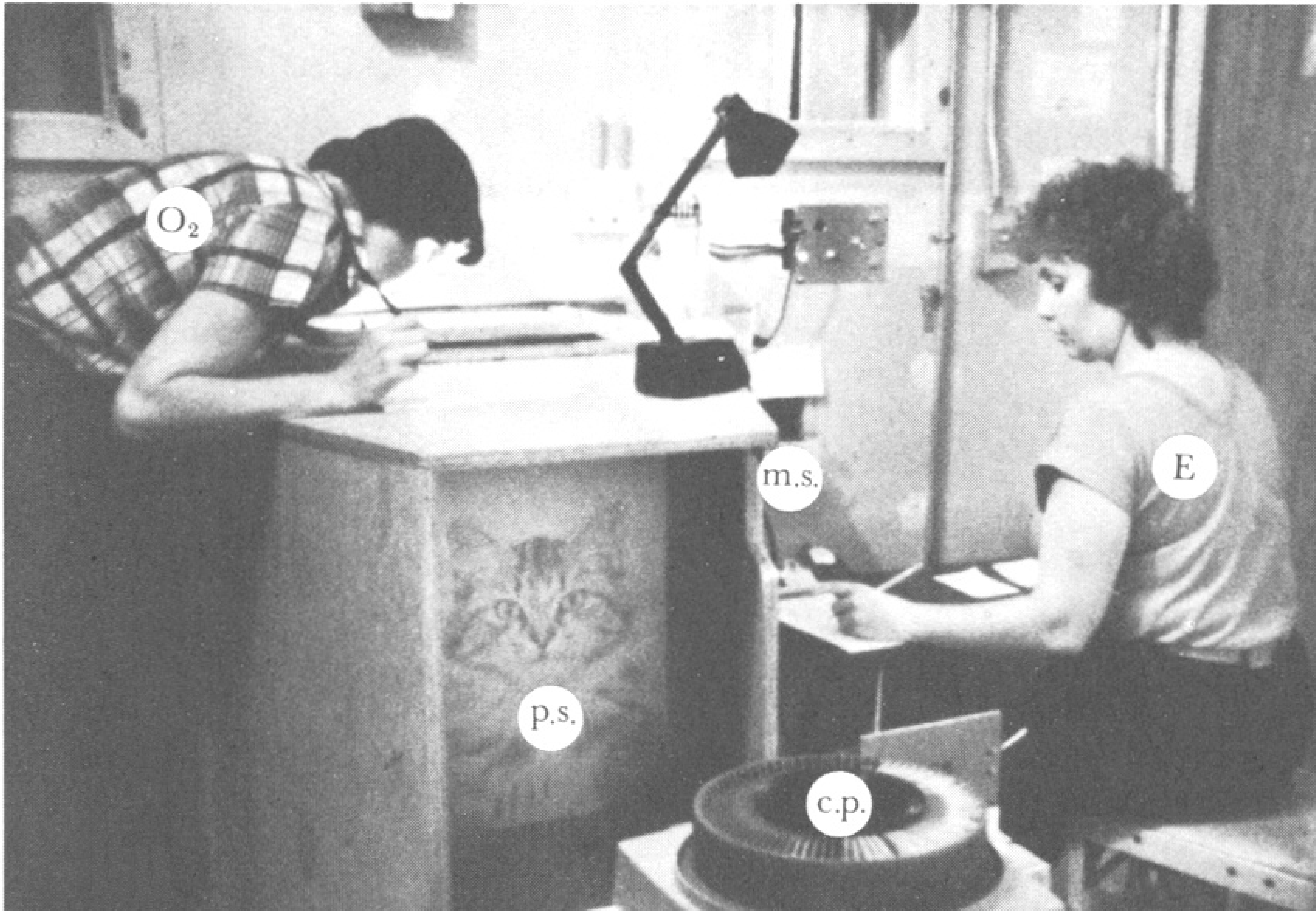
Watson, D. O. 1973 *Talk with your hands*. Menasha, Wisconsin: George Banta, Company, Inc.

Watt, W. C. 1974 Review of A. M. Schrier & F. Stollnitz (eds), *Behavior of nonhuman primates*. *Behav. Sci.* **19**, 70–75.

Yerkes, R. M. & Yerkes, A. W. 1929 *The great apes: A study of anthropoid life*. New Haven: Yale University Press.



GURE 1. Room 1 of the vocabulary testing apparatus used with Moja, Tatu, and Dar. Chimpanzee Dar sits in front of the projection screen, which is recessed within the cabinet. O_1, seated beside the cabinet, can see Dar's signs but cannot see the projecton screen. By pressing the white push-button (b.), Dar makes a picture appear on the screen. (The vocabularly testing apparatus used with Washoe was slightly different; see Gardner & Gardner, 1974*a*, pp. 11–16).



GURE 2. Room 2: a carousel projector (c.p.) shows the slides. Standing to one side of the cabinet, O_2 can see the subject through the one-way glass window but cannot see the projection screen (p.s.). O_2 writes down what the subject signs and passes the message slip to the experimenter (E), who also receives written messages from O_1, via the message slot (m.s.). After receiving a message slip from O_1 and O_2, E. steps the carousel to the slide for the next trial.

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