Form Perception and Visual Acuity in a Chimpanzee

Tetsuro Matsuzawa
Primate Research Institute, Kyoto University, Inuyama, Japan

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Abstract. A 6.5-year-old female chimpanzee learned to distinguish perfectly every letter of the alphabet in a matching-to-sample task with 26 letters as choice alternatives. Confusion of letters during the initial training was used to scale them in a multidimensional similarity space and to associate them in hierarchical clusters. The results resembled those obtained from similarity judgements by humans. Using letters of various sizes, a visual acuity test revealed that the chimpanzee’s acuity was about 1.5, comparable to that in normal humans. The chimpanzee also readily learned to use letters as names of individual humans and chimpanzees. A species-typical feature was identified in the perceptual processes associated with complex forms, such as those involved in individual recognition.

Introduction

How does a chimpanzee perceive the world? What differences are there between human and chimpanzee perception? Although the visual system of chimpanzees is quite similar to that of humans [1], there is little behavioural evidence indicating the perceptual world of the chimpanzee [2]. The present study aimed, first, to investigate form perception of the upper case letters of the Roman alphabet by the chimpanzee. The letters of the alphabet constitute a relatively simple perceptual context, and they have accordingly been used in studying form perception in both humans [3] and pigeons [4]. Secondly, the letters were used to investigate visual acuity in the chimpanzee, following exactly the same procedure as that adopted for humans. Finally, the letters were used as ‘names’ of individual humans and chimpanzees to explore the nature of the more complex perceptual/cognitive processes such as ‘individual recognition’ in the chimpanzee.

Methods

Subject
The subject was 6.5-year-old female chimpanzee, ‘Ai’, born in Africa and received in the laboratory at about 1 year of age. Prior to this study, she had been
-employed for about 5 years in a training program for language-like skills [2, 5-9]. This chimpanzee had extensive experience of matching-to-sample tasks, but she had never previously seen the letters of the alphabet. The normal daily feeding schedule was maintained without food deprivation. A social relationship between the subject and the experimenter was established during a 'social hour' in the playground every afternoon, but social interaction was eliminated in the computer-controlled experimental situation.

Apparatus
Ai was housed in a group home cage with 3 other chimpanzees of the same age and was carried by hand for the experiment. The chimpanzee was placed in an experimental room (1.8 x 1.8 x 2 m) with a console terminal interfaced to a PDP11/VO3 minicomputer. Each letter of the alphabet was drawn on a key (2 x 2.5 cm) in a 5 x 6 key matrix on the console (fig. 1).

Stimuli
The letter format was the standard 'Helvetica medium 48 points (Letraset No. 721)'. Each letter was provided on a sheet of white cardboard (B6 size) as a sample and on a key as a choice alternative. In the final experiment on individual recognition, each sample photograph (8 x 11.5 cm) of humans or chimpanzees was attached to a similar sheet of white cardboard.
Procedure: Discrimination of Letters

The experimenter exposed letters, one at a time, on white cardboard. The chimpanzee sat about 50 cm away on a bench in front of the console. While exposing the letter as a sample, the experimenter lit up the 30-key matrix on the console containing 26 letters and 4 blank ineffective keys. The chimpanzee was required to press one key among 26 alternatives. The position of the letters on the keys was randomly changed from session to session to prevent the chimpanzee from memorizing positional cues.

Correct and incorrect responses were followed by different feedback sounds, a chime and a beep, respectively. A piece of apple or a raisin was automatically delivered after each correct response. Key choice and response latency (the interval from letter presentation to key choice) were recorded on a computer disc. A trial took place once every 15 s on average. A daily session consisted of five blocks of 26 trials. Each letter was randomly presented as a sample once in each block. Confusion that occurred during the first 10 sessions provided the data for representing the perception of letters.

Procedure: Perception of Letters

Perception of letters was represented by a two-dimensional plot based on multidimensional scaling and also by a hierarchical cluster analysis. The details are described in the relevant section. To compare letter perception in a chimpanzee directly to that in humans, human data were also collected for the same letter format. The human data were obtained by the direct similarity judgement of each letter pair, following the procedure of Podgorny and Garner [3]. The human subjects were D.W. (adult female) and T.M. (adult male, the investigator). Both of them had normal vision. The averaged data of 2 human adults were used for comparison with the chimpanzee.

Procedure: Size Generalization

In training from the 11th session onwards, a correction method was introduced. An incorrect choice caused the same sample to be repeated in the next trial, and 2 consecutive correct trials were required for a reward. When matching-to-sample reached an almost perfect level (above 98.0% accuracy in 130 trials per daily session in 2 consecutive days), the size of the letters used as samples was varied. In the generalization test, letters in 12, 16, 24, 36, 72, 96, 144 and 192 points were used in addition to the standard (48 points). All other procedures were the same as those in the first 10 sessions.

Procedure: Visual Acuity Test

The distance between the chimpanzee and the sample letter was gradually increased. Finally, following the convenient standard procedure for visual acuity testing, the distance was set at 3 m, and the letter was illuminated by a daylight fluorescent bulb approximating the proper CIE illuminant D (the standard light close to outdoor daylight). The number of test letters was reduced from 26 to 10 for convenience: A, K, L, M, O, P, S, T, X, Z. The sizes of the letters varied in 12 steps from 192 to 6 points. A test session consisted of 60 trials. On the first trial, the largest letter (192 points) was shown as a sample. If it was detected correctly, a letter one step smaller was presented in the next trial, and so on. If the incorrect key was chosen, a letter one step larger was presented in the next trial.

This up-down (staircase) method maintains performance near the detection threshold. The procedure described above is referred to as having an up-down ratio of 1:1. The tests were carried out with an up-down ratio of 1:1 and also at ratios of 1:2 or 2:1. Visual acuity was tested in a total of 8 sessions.

Procedure: Individual Recognition

After near-perfect letter discrimination had been established, Ai learned to utilize the letters as names of individual humans and chimpanzees. She mastered a symbolic matching-to-sample task in which each photograph (front view of the face) of 10 familiar individuals, 5 humans and 5 chimpanzees, had to be matched to an arbitrarily assigned letter. The letters K (Kiyoko), S (Shozo), T (Toshio), X (Junzo), Z (Tetsuro) represented 5 humans, and the letters A (Akira), L (Ai herself), M (Mari), O (Popo), P (Pendey) represented 5 chimpanzees. Both sexes were included. All individuals were familiar to Ai. She had been acquainted with all individuals concerned for 1.5—5.5 years. (Of course, she 'recognized' her own face. According to a 'self-recognition' test similar to Gallup's [10], Ai when marked with red dye showed evidence of being able to recognize her own reflections in mirrors). While exposing a photograph as a sample, the experimenter lit up the key matrix on the console containing the 10 letter keys. The other procedures were the same as those in the previous stages.
Fig. 2. The acquisition of discrimination on all letters of the alphabet in a matching-to-sample task with 26 letters as choice alternatives. Solid circles represent performance excluding the correction trials. Open circles represent performance including the correction trials. In the transfer test, the size of the letters was varied. Solid triangles represent the performance for the newly introduced sizes of letters.

In the transfer test, 16 different sets of photographs for the same individual humans and chimpanzees were prepared. Each set of 10 individuals was shown in different views, such as front view, side view, face only, upper body and whole body. Humans had distinctive clothing or the same clothing.

Results

Discrimination of Letters

Although the chimpanzee had never previously seen the Roman alphabet, her accuracy was 41.5% in the first session (chance level is below 4%, $p \leq 0.001$ in $\chi^2$ test) and rose to 66.2% in the final 10th session (fig. 2).

In the first trial of the first session, the sample letter was ‘B’. The chimpanzee repeatedly looked at the sample and the choice letters, and then finally pressed the key ‘F’. The response latency of the first trial was 114 s. Response latency gradually decreased to about 4.0 s on average (range: 1.2–11.3 s) in the 10th session.

Perception of Letters

A sample choice ‘confusion matrix’ was computed over the first 10 sessions in which each letter appeared as a sample 50 times in total. The confusion matrix was then ‘folded’ to give a similarity index for each letter pair. The similarity index used in the present study is a modified version of Shepard’s index [11]. The similarity ($S_{ij}$) between two letters $i$ and $j$ is defined by the following equation: $S_{ij} = [P(i/j) + P(j/i)]/[P(i/i) + P(i/j)]$, in which $P(i/j)$ means the conditional probability of choosing the letter $i$ during presentation of the letter $j$. The value of $S_{ij}$ varies from 0 (no confusion between the two letters; perfect dissimilarity) to 1 (no discrimination; perfect similarity).

The resulting half-matrix of the similarity index was used for multidimensional scaling of the similarity of the letters with ALSCAL [12]. ALSCAL (alternating least squares multidimensional scaling algorithm) was run in a version (4.03, 1981) provided by the SAS (SAS Institute, Cary, N.C., USA). The
sions in figure 3, suggest distinctive features, such as ‘roundness’ and ‘simplicity’. It must be also noted that those pairs of letters that give the shortest branches of the tree (in other words, the most visually similar pairs) differ only by a small discrepancy in physical matching (fig. 4).

Correlation provides a quantitative measure of the relation between similarity matrices. The product-moment correlation between the chimpanzee data and the human data based on similarity judgement for the same letter format was $r = 0.61$, comparable to the correlation between different investigations of human subjects. Podgorny and Garner [3] report a correlation of $r = 0.59$ between judgement of letter similarity and reaction time analysis for a same-different discrimination task in humans. The correlation between the two sets of similarity judgement data for humans, that from the present study and that from the study of Podgorny and Garner, was $r = 0.78$, although the letter formats were different (the other study used a dot-matrix letter format). The results clearly show that the difference in data-collecting techniques influenced the similarity data as much or more than the difference in the letter format. The results indicate that there is a common basis for the perception of form in chimpanzees and humans.

Size Generalization

Introduction of the correction method improved performance of matching-to-sample. In the following 13 daily sessions, performance reached an almost perfect level (above 98.0% accuracy in 2 consecutive days). The sizes of the letters were then varied. The generalization decrement was initially more marked for the smaller letters than for the larger ones (fig. 5). Six sessions
of the generalization training made the performance almost perfect in spite of the size variation (fig. 2).

Visual Acuity Test
The absolute threshold of letter detection was assessed in each test session by using the up-down method (fig. 6). The data of 8 test sessions were combined to determine the percent correctness at each size of the letters. Although the difference in up-down ratios inevitably entails a difference in reinforcement probability (50% reinforcement at ratio 1:1, 66% at ratio 2:1 and 33% at ratio 1:2, respectively, when performance is maintained at the threshold level), the absolute
threshold of letter detection remained unchanged. The accuracy of letter detection was plotted against the letter size (fig. 7).

The absolute threshold of detection was 12 points in size: letters larger than 3 mm in height were detectable at a distance of 3 m by the chimpanzee. The minimum separable visual acuity using the Landolt C ring is defined as the reciprocal of the minimum visual angle of the gap. A visual acuity of 1.0 means that the subject discriminates a visual angle of 1'. When visual acuity in letter identification is concerned, the height of the letter is converted to the height (diameter) of the Landolt C ring for the calculation. The binocular visual acuity of the chimpanzee was evaluated as 1.5, which is comparable to that of normal humans. The present study followed exactly the same procedure adopted in the standard visual acuity test in humans. The obtained visual acuity was congruent with the data assessed for 2 chimpanzees with a different method [13] and also with the data for macaques [14, 15].

**Individual Recognition**

Once letter discrimination had been established, Ai quickly learned to utilize the letters as names of individual humans and
Table 1. Frequency of types of confusion appearing in individual recognition, based on Ai’s incorrect responses in the transfer tests for naming various photographs of individual humans and chimpanzees

<table>
<thead>
<tr>
<th>Incorrect naming</th>
<th>Photographs shown as samples</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>humans</td>
<td>chimpanzees</td>
<td></td>
</tr>
<tr>
<td>Incorrect</td>
<td>119 (70%)</td>
<td>0 (0%)</td>
<td></td>
</tr>
<tr>
<td>human names</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrect</td>
<td>12 (7%)</td>
<td>38 (23%)</td>
<td></td>
</tr>
<tr>
<td>chimpanzee names</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discussion

The series of experiments reported here strongly suggests that the perceptual world of the chimpanzee is equivalent to that of humans and yet may have some special features of its own.

The perceptual process for simple shapes, such as the letters of the alphabet, seems to have a common basis in chimpanzees and humans, which may also be shared to some extent by other species such as pigeons. Assessment of the visual acuity of the chimpanzee shows that there is no fundamental difference in acuity between humans, chimpanzees and macaques [13–15]. However, the chimpanzee can perfectly distinguish each letter of the alphabet and use the letter system to represent the perceptual world, as humans do.

Assessment of the ‘naming’ skill acquired by the chimpanzee indicates that the perceptual processes of complex form, such as those involved in individual recognition, have a species-typical character. Because the letters of the alphabet were almost perfectly discriminated by the chimpanzee, the confusion in the individual recognition task described above must be due to the perceptual similarity among the individuals. It is interesting to note that the results of the chimpanzee contrast with the similarity judgements performed by the human observers. For humans, the photographs of chimpanzees looked alike, while those of humans looked different.

In a further test conducted to require naming of 2 individuals in any order when 2 photographs were presented simultaneously, the chimpanzee showed a tendency to name chimpanzees before humans. This ‘species-centric’ kind of individual recognition found in the chimpanzee is reported in more detail elsewhere [9].
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References


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Tetsuro Matsuzawa
Primate Research Institute
Kyoto University
Inuyama
Aichi 484 (Japan)