Primates
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ORIGINAL ARTICLE

Learning the rules of the rock–paper–scissors game: chimpanzees versus children

Jie Gao[1,2] · Yanjie Su[3] · Masaki Tomonaga[1] · Tetsuro Matsuzawa[1,4,5]

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Abstract The present study aimed to investigate whether chimpanzees (*Pan troglodytes*) could learn a transverse pattern by being trained in the rules of the rock–paper–scissors game in which "paper" beats "rock," "rock" beats "scissors," and "scissors" beats "paper." Additionally, this study compared the learning processes between chimpanzees and children. Seven chimpanzees were tested using a computer-controlled task. They were trained to choose the stronger of two options according to the game rules. The chimpanzees first engaged in the paper–rock sessions until they reached the learning criterion. Subsequently, they engaged in the rock–scissors and scissors–paper sessions, before progressing to sessions with all three pairs mixed. Five of the seven chimpanzees completed training after a mean of 307 sessions, which indicates that they learned the circular pattern. The chimpanzees required more scissors–paper sessions (14.29 ± 6.89), the third learnt pair, than paper–rock (1.71 ± 0.18) and rock–scissors (3.14 ± 0.70) sessions, suggesting they had difficulty finalizing the circularity. The chimpanzees then received generalization tests using new stimuli, which they learned quickly. A similar procedure was performed with children (35–71 months, $n = 38$) who needed the same number of trials for all three pairs during single-paired sessions. Their accuracy during the mixed-pair sessions improved with age and was better than chance from 50 months of age, which indicates that the ability to solve the transverse patterning problem might develop at around 4 years of age. The present findings show that chimpanzees were able to learn the task but had difficulties with circularity, whereas children learned the task more easily and developed the relevant ability at approximately 4 years of age. Furthermore, the chimpanzees' performance during the mixed-pair sessions was similar to that of 4-year-old children during the corresponding stage of training.

Keywords Rule learning · Comparative cognition · Transverse pattern · Circular relationships · Non-linear relationships

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✉ Tetsuro Matsuzawa
matsuzawa.tetsuro.8w@kyoto-u.ac.jp

[1] Primate Research Institute, Kyoto University, Inuyama, Japan

[2] School of Life Sciences, Peking University, Beijing, China

[3] School of Psychological and Cognitive Sciences and Beijing Key Laboratory of Behavior and Mental Health, Peking University, Beijing, China

[4] Institute for Advanced Study, Kyoto University, Kyoto, Japan

[5] Japan Monkey Centre, Inuyama, Japan

Introduction

Transverse patterning tasks represent the simplest circular relationships. In these tasks, there are three elements (A, B, and C) with the relationships A+B−, B+C−, and C+A−, where the plus sign indicates that the corresponding element is preferred and the minus sign indicates that it is less preferred (Spence 1952). The relationships are non-linear. The stimuli must be understood in a configural way (here, in pairs), because no element has a consistent value (i.e., it is always the stronger one) in an individual manner. It is well known that certain species are adept at understanding linear relationships; for example they are able to use transitive inference to infer other individuals' dominance

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status without challenging each of them directly. This saves a significant amount of energy and increases fitness (reviewed in Vasconcelos 2008). However, non-linear relationships also play a crucial role in the lives of animals. More specifically, transverse patterning requires animals to pick the elements configurally instead of understanding the pattern by simple discrimination. This type of mental process might be needed in complex relationship network building, knowledge updating, and problem solving (Hull 1943; Spence 1952; Astur and Sutherland 1998). Monkeys, rats and pigeons are able to complete the transverse patterning task, with rats and pigeons showing difficulties in learning the third pair compared to the first and the second pairs (Alvarado and Rudy 1992; Couvillon and Bitterman 1996; Wynne 1996; Nejime et al. 2015).

Thompson (1953) studied figure discrimination in a transverse patterning task in five preadolescent male chimpanzees, four of which were able to complete the task. However, these findings did not address whether chimpanzees showed similar learning patterns to rats and pigeons. Additionally, because the participants were all preadolescent males, the effects of age and sex on performance in the transverse patterning task remain unknown. Gillan (1981) trained a young female chimpanzee (Sadie) on a task with several contingencies (A+B−, B+C−, C+D−, D+E−, and E+F−) and reported that she could choose correctly between the tasks after training. When then introduced to F+A−, it took a long time for her to reach the learning criterion, and the learning of F+A− affected her performance in the A+B− and E+F− sessions. These findings indicate that Sadie may have experienced difficulties completing circularity, but this was not examined in detail.

Human adults have been shown to complete transverse patterning tasks (Astur and Sutherland 1998; Gross and Greene 2007; Carlozzi and Thomas 2008), but they needed more trials to learn the third pair of the tasks (Carlozzi and Thomas 2008). Children can solve the transverse patterning problem after the age of 4.5 years (Rudy et al. 1993). However, whether humans and chimpanzees are comparable in their ability to perform this task remains unknown. Therefore, the present study tested both chimpanzees and children on transverse patterning tasks. Seven chimpanzees participated in experiment 1, including three young adults and four older adults. Thirty-eight children aged between 31 and 71 months participated in experiment 2; this age range included the critical age (4.5 years old) suggested by Rudy et al. (1993). To simplify the experiments, the rules of the rock–paper–scissors game were adapted such that “paper” was preferred over “rock,” “rock” was preferred over “scissors,” and “scissors” was preferred over “paper.”

Methods

Experiment 1: chimpanzees

The first experiment aimed to systematically investigate whether chimpanzees could learn the circular relationship involved in the rules of the rock–paper–scissors game and, if they could, determine the manner in which they learned it.

Participants

Seven chimpanzees belonging to two social groups with a total of 13 individuals participated in the experiments (Table 1). They lived at the Primate Research Institute, Kyoto University (KUPRI; Inuyama, Aichi, Japan) in an environment with an outdoor compound (700 m^2) and connected indoor compounds (Matsuzawa et al. 2006); the outdoor compound was an enriched environment with climbing facilities (15-m high), a stream, and many trees species (Ochiai and Matsuzawa 1997). All chimpanzees had full access to food and water throughout the study and had previous experience with computer-controlled cognitive tasks including numerical competence, the acquisition and use of a visual artificial language, short-term memory, facial recognition, visual search and attention, and visual perception (Matsuzawa 2001, 2003; Tomonaga 2001; Matsuzawa et al. 2006). The care and use of the chimpanzees adhered to the 2010 Guidelines for the Care and Use of Laboratory Primates of KUPRI, and the research proposal was approved by the Animal Welfare and Animal Care Committee of KUPRI and the Animal Research Committee of Kyoto University. All procedures adhered to the Japanese Act on Welfare and Management of Animals.

Apparatus

The participants sat in an experimental booth and performed the tasks on a 15-inch LCD touch screen (1024 × 768 pixels; Fig. 1). When the chimpanzees made the correct choice in a trial, a piece of apple was provided via a feeder in conjunction with a chime sound. When the wrong stimulus was chosen, an error buzzer sounded, and no food was provided. The food reward was delivered through a universal feeder to a food tray placed at the bottom of the display. All experimental events were controlled by a computer, and the experimental programs were written and operated with Microsoft Visual Basic 2010 software (Microsoft, Redmond, WA).

Table 1 General characteristics of the seven chimpanzees

Name	GAIN ID number[a]	Sex	Age (when the study started)	Kinship
Ai	0434	Female	38	Ayumu's mother
Ayumu	0608	Male	14	Ai's son
Chloe	0441	Female	34	Cleo's mother
Cleo	0609	Female	14	Chloe's daughter
Pan	0440	Female	31	Pal's mother
Pal	0611	Female	14	Pan's daughter; Ayumu's sibling
Pendesa	0095	Female	38	NA

[a] Identification number (*ID*)for each chimpanzee listed in the database of the Great Ape Information Network (GAIN); https://shigen.nig.ac.jp/gain/

Fig. 1 Chimpanzee Ai carrying out a task on the touch screen

Stimuli

One set of stimuli was used for the training phase (chimp hand 1; Fig. 2), and five sets of stimuli were used for the generalization phase (chimp hands 2 and 3 and human hands 1, 2, and 3). In each set, the three photographs represented rock, paper, and scissors. The original photographs were manipulated using Adobe Photoshop software (Adobe Systems, San Jose, CA).

Procedure

Each chimpanzee typically engaged in three 48-trial sessions on a daily basis. In each trial, a 2-s inter-trial interval (ITI) was followed by a black circle (start key) that was presented at the center bottom of a screen with a white background. When the chimpanzee touched the start key, the black circle disappeared and two stimuli were shown side-by-side as response options (Fig. 1). Both stimuli disappeared when the participant touched either one of them. If the chimpanzee touched a stimulus predefined as "correct" (paper in the paper–rock pair, rock in the rock–scissors pair, and scissors in the scissors–paper pair), a piece of apple was delivered as a reward and a chime sounded. If the chimpanzee chose an incorrect stimulus, only the buzzer sounded; the timeout duration was 3 s.

Fig. 2 Six sets of stimuli were used. From *top* to *bottom* the stimuli were pictures of chimpanzee and human hands, numbered 1, 2, and 3, respectively. From *left* to *right* the three stimuli in each set represent paper, rock, and scissors, respectively. In the training phase, chimpanzees were presented with the chimp hand 1 stimuli and the other five sets of stimuli during the generalization tests. Children were exposed to the human hand 1 stimuli in experiment 2

During the training phase, chimpanzees first participated in paper–rock sessions in which all trials were paper–rock pairs. After reaching a score of 90% correct responses, they participated in rock–scissors sessions and then scissors–paper sessions using the same criterion. In principle, after achieving 90% correct responses in the scissors–paper sessions, they participated in paper–rock sessions again and this cycle was repeated, until 90% correct responses were obtained in one paper–rock session followed by one rock–scissors session and then by one scissors–paper session. After completing these single-pair sessions, the chimpanzees participated in sessions in which the three pairs were mixed. The first mixed sessions included 16-trial blocks in which there were 16 consecutive same pairs, 16 consecutive trials of another same pair, and then 16 trials of a third same pair. After reaching 90% accuracy across all trials and no more than one error in each block for three consecutive sessions, the chimpanzees entered the next phase, which included eight-trial blocks. After reaching the criterion in the eight-trial block phase, the chimpanzees progressed to the next phase, which included four-trial blocks. Finally, a random condition was presented in which the three pairs were randomly distributed within a 48-trial session; the criterion for completing the training was 90% accuracy and a maximum of two errors for each pair for three consecutive sessions.

The chimpanzees that completed the training received generalization tests in which the other five sets of stimuli were used (Fig. 2). All sessions were presented under random conditions, and the same criterion as the final criterion in the training phase was adopted. In the generalization tests, the human hand 1 stimuli were presented first along with the original stimuli (chimp hand 1) as the baseline. After reaching the criterion for human hand 1, we presented human hand 2, human hand 3, chimp hand 2, and chimp hand 3 with the learned sets. Freeware was used for all the statistical analyses (R 3.3.1; R Core Team 2016).

Experiment 2: children

Participants

A total of 38 children (17 females and 21 males) ranging from 35 to 71 months old (mean 54 months, SD = 10.02) were recruited from a kindergarten in Xinxiang, Henan, China. The experimenter and the kindergarten administrators informed the children and their parents with a letter of consent, and the participants and their parents voluntarily agreed to participate in the study. The experiment was conducted in the kindergarten after written approval from the parents of each participant had been received. After the experiment, the children received cartoon stickers as a reward for their participation, regardless of their performance. The participants and their parents had the right to withdraw from the study at any time, and the research proposal was approved by the Human Research Ethics Committee of KUPRI.

Apparatus

The participants performed the tasks on a touch-screen laptop computer with a 14-inch LCD display (1,366 × 768 pixels; Lenovo S400 Touch) in a room in the kindergarten that also contained the experimenter and their teachers; all experimental events were controlled by the laptop. When the participants made the correct choice, a chime sound was presented with a positive picture of infant chimpanzees playing. When the wrong stimulus was chosen, no sound or picture was presented. The experimental programs were written and operated using Microsoft Visual Basic 2010 software (Microsoft).

Stimuli

The human hand 1 stimuli were used to test the children (Fig. 2).

Procedure

The overall procedure of experiment 2 was similar to that of experiment 1, but the details were altered to fit the situation of the children. Each participant engaged in a maximum of four 12-trial sessions. First, the children participated in paper–rock sessions; if four consecutive correct choices were made, the next session involved rock–scissors. After the rock–scissors sessions came scissors-paper sessions. If children completed those sessions in the first three sessions, they received a random session for their last session. The procedure for each individual trial was also similar to that of experiment 1 except for the feedback aspect: for the children, correct responses resulted in a chime and a picture of infant chimpanzees playing, and nothing was presented following an incorrect choice. The ITI was 0, the timeout duration was 1 s, and the experimenter explicitly told the participant when the correct choice was made immediately after that choice. Unambiguous suggestions, such as “try again” were offered when children made errors. Generalized linear mixed model (GLMM) analyses were conducted using the lme4 package of R to assess the data (Bates et al. 2015).

Results

Experiment 1: chimpanzees

Five of the seven chimpanzees, Ai, Ayumu, Chloe, Pal, and Pendesa, completed the training phase after 533, 161, 310,

Table 2 Numbers of sessions needed to complete the training and generalization tests

Stimuli	Ai	Ayumu	Chloe	Pal	Pendesa
(Training) chimp hand 1	533	161	310	245	286
(Generalization) chimp hand 2	43	NA	25	30	38
(Generalization) chimp hand 3	71	NA	32	18	NA
(Generalization) human hand 1	59	NA	23	72	70
(Generalization) human hand 2	22	NA	38	27	76
(Generalization) human hand 3	29	NA	29	32	38

NA Not available

245, and 286 sessions, respectively (mean 307.00 ± 61.92; Table 2), indicating that the chimpanzees were able to learn the circular relationship. The other two chimpanzees, Cleo and Pan, were still performing the first half of the stages of the training phase after 727 and 652 sessions, respectively.

Figure 3 depicts the learning curves of the chimpanzees; the vertical axis shows the percentage of correct trials per session, the horizontal axis shows the sessions, and the curves with different marks represent different session conditions. These graphs illustrate improved performances throughout training, particularly during the single-pair sessions. Performance tended to fluctuate in the mixed-pair sessions but gradually improved over time until the chimpanzees entered the next phase, in which performance clearly dropped, particularly with respect to the first phase of the single-pair condition. When performance was at a high level, and participants passed the condition entry criterion, performance in the first session under the new condition deteriorated severely. For example, when the chimpanzees initially shifted from the paper–rock sessions to the rock–scissors sessions, their performances decreased from 100 to 54% (Ai), 100 to 63% (Ayumu), 100 to 85% (Chloe), 100 to 25% (Cleo), 96 to 50% (Pan), 100 to 65% (Pal), and 96 to 31% (Pendesa) in the latter sessions. These results can be explained by the reversal of the contingency of rock within the pairs from non-rewarded to rewarded, and the same explanation can be applied to the transfer from the rock–scissors sessions to the scissors–paper sessions. Pal, Pendesa, Chloe, Ai, and Ayumu gradually learned that the correct answers for the three pairs differed and that the pairs always shared one element, which indicates that they understood the circular relationship among the three elements to a certain extent. However, Pan and Cleo experienced greater difficulties, and their performances dropped precipitously when changing to a new pair. These difficulties were characterized by confusion regarding the overlapping elements.

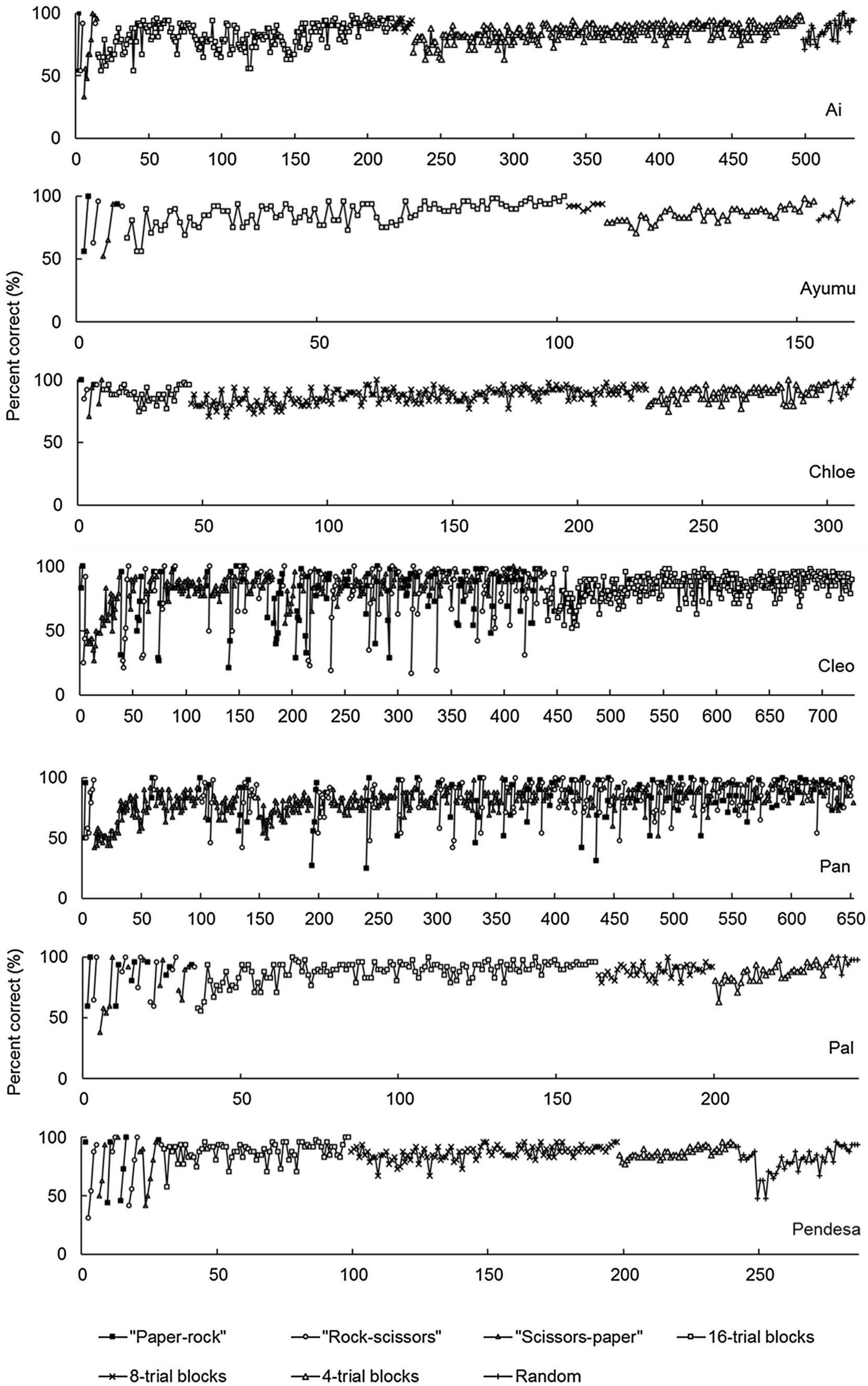
Figure 4 shows the number of sessions taken to complete the first paper–rock, rock–scissors, and scissors–paper sessions. The chimpanzees required more sessions (14.29 ± 6.89) to complete the third pair (scissors–paper), but fewer sessions were needed for the second training pair, rock–scissors (3.14 ± 0.70) and the first training pair, paper–rock (1.71 ± 0.18). Significant differences in learning performance were detected among the pairs (Kruskal–Wallis rank sum test, $\chi^2 = 10.684$, $df = 2$, $p = 0.005$), and multiple comparison tests revealed that significantly more scissors–paper sessions were required than paper–rock sessions (two-tailed Dunn's multiple comparison test with Holm's adjustment following a significant Kruskall–Wallis test, $z = 3.27$, $p = 0.003$), indicating difficulties in completing the circularity. This was particularly true for Cleo (32 sessions for scissors–paper) and Pan (48 sessions for scissors–paper).

The five chimpanzees that completed the training received generalization tests with different stimuli. Chloe, Pal and Ai completed all generalization conditions, Pendesa completed some, whereas Ayumu did not complete the human hand 1 stimuli and therefore did not progress to the other four generalization sets (Table 2). The generalization tests were all performed under random conditions; therefore direct comparisons of the training and generalization sessions were not performed. Nevertheless, fewer sessions were needed to complete the generalization tests than the training tests. Together with the fact that they reached the criterion with the new stimuli, the results clearly show the chimpanzees' ability to learn the circular relationship.

We also examined the chimpanzees' performances during their first sessions with the first new stimuli, human hand 1: the accuracy scores of Ai, Ayumu, Chloe, Pal, and Pendesa were 54, 54, 52, 44, and 48%, respectively (binomial test p-values = 0.66, 0.66, 0.88, 0.47, and 0.89, respectively), which were not significantly different from chance. This suggests that the chimpanzees might have had some difficulty generalizing the circular relationship at first.

Experiment 2: children

Of the 38 children that participated in experiment 2, thirty-four [14 females, 20 males; age, 35–71 months (mean = 54.47, SD = 10.35)] reached the criterion for


Percent correct (%)
Ai
Ayumu
Chloe
Cleo
Pan
Pal
Pendesa
"Paper-rock"
"Rock-scissors"
"Scissors-paper"
16-trial blocks
8-trial blocks
4-trial blocks
Random

◀**Fig. 3** Learning curves of chimpanzees during training. *Part 1* Learning curves of chimpanzees Ai, Ayumu, Chloe, and Cleo; *part 2* learning curves of chimpanzees Pan, Pal, and Pendesa

the three pairs in the first three sessions and received a random session for their final session. Of the remaining four children, one (male, 61 months) declined to participate in the fourth session after reaching the criterion for all three pairs, two (females, 45 and 49 months old) performed two paper–rock sessions among the four sessions in which they engaged, and one (female, 50 months old) performed two rock–scissors sessions among the four sessions. The average number of trials needed by all children ($n = 38$) to reach the criterion under all conditions was 5.83 ± 0.25. For each condition, the average numbers of trials needed was 6.68 ± 0.53 for paper–rock, 5.87 ± 0.43 for rock–scissors, and 4.95 ± 0.22 for scissors–paper. The average accuracy in the random sessions ($n = 34$) was 70 ± 4.8%.

GLMM analyses were conducted to assess the numbers of trials under all conditions, and we also conducted leave-one-out cross-validation using the drop1 function. Condition, age, and gender were set as fixed factors, and participant identification number (ID) was set as the random factor. The analysis revealed that condition ($\chi^2 = 1.40$, $df = 2$, $p = 0.50$), age ($\chi^2 = 1.04$, $df = 1$, $p = 0.31$), and gender ($\chi^2 = 0.13$, $df = 1$, $p = 0.72$) did not have a significant effect on the number of trials. These findings suggest that the children had no difficulties learning the final pair to complete the circularity, in contrast to the chimpanzees.

Next, the data obtained under each condition were analyzed. The numbers of trials needed to reach criterion were not influenced by gender (paper–rock condition, $\chi^2 = 0.17$, $df = 1$, $p = 0.68$; rock–scissors condition, $\chi^2 = 0.00022$, $df = 1$, $p = 0.99$; scissors–paper condition, $\chi^2 = 0.05$, $df = 1$, $p = 0.83$) or age (paper–rock condition, $\chi^2 = 0.50$, $df = 1$, $p = 0.48$; rock–scissors condition, $\chi^2 = 0.44$, $df = 1$, $p = 0.51$; scissors–paper condition, $\chi^2 = 0.15$, $df = 1$, $p = 0.70$), which further demonstrates the lack of difficulty in learning the three pairs.

Performances in the random sessions ($n = 34$) were also evaluated using GLMM analyses with age and gender as fixed factors and participant ID as the random factor, and we also conducted leave-one-out cross-validation using the drop1 function. Accuracy in the random session could be explained by age ($\chi^2 = 29.39$, $df = 1$, $p < 0.001$) but not gender ($\chi^2 = 1.63$, $df = 1$, $p = 0.20$). The variance estimate of the random effect, participant ID, was 0.65 (SD 0.80). We then tried other models instead of the full model, and chose the best-fitted model based on Akaike information criterion (AIC) values. The model with age as the fixed effect and participant ID as the random effect had the lowest AIC value. In this model, the estimate of the variance of the random effect, participant ID, was 0.74, and the SD was 0.86; the estimate of the fixed effect, age, was 0.14, the SE was 0.023, the z-value was 5.99, and the p-value <0.001; the estimate of the intercept was −6.27, the SE was 1.20, the z-value was −5.22, and the p-value < 0.001. The leave-one-out cross-validation of this model also revealed a significant effect of age ($\chi^2 = 30.64$, $df = 1$, $p < 0.001$).

The probability of a correct choice was calculated using the logit link function of the model: $P = 1/(1+e^{-(-6.27+0.14\times \mathrm{Age})})$; this probability was considered to be the predicted accuracy. Performance in the random sessions improved with age. Also, the predicted accuracy of 67%, which differed from a chance level of 50% (binomial test $p < 0.05$), fell at 50 months of age (Fig. 5). Thus, children may develop the ability to learn a circular relationship from about 50 months of age, and performance improved as age increased.

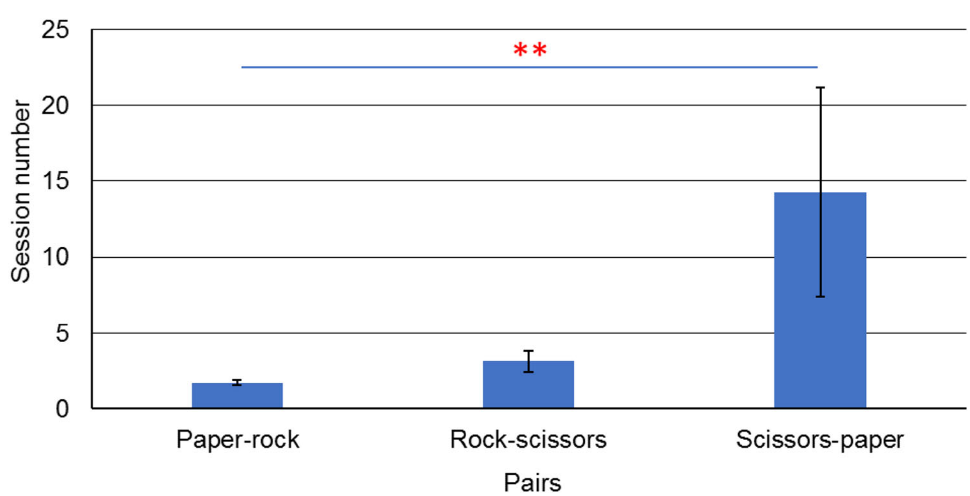


Fig. 4 Numbers of sessions needed by chimpanzees to complete the first paper–rock, rock–scissors, and scissors–paper sessions. **$P < 0.01$

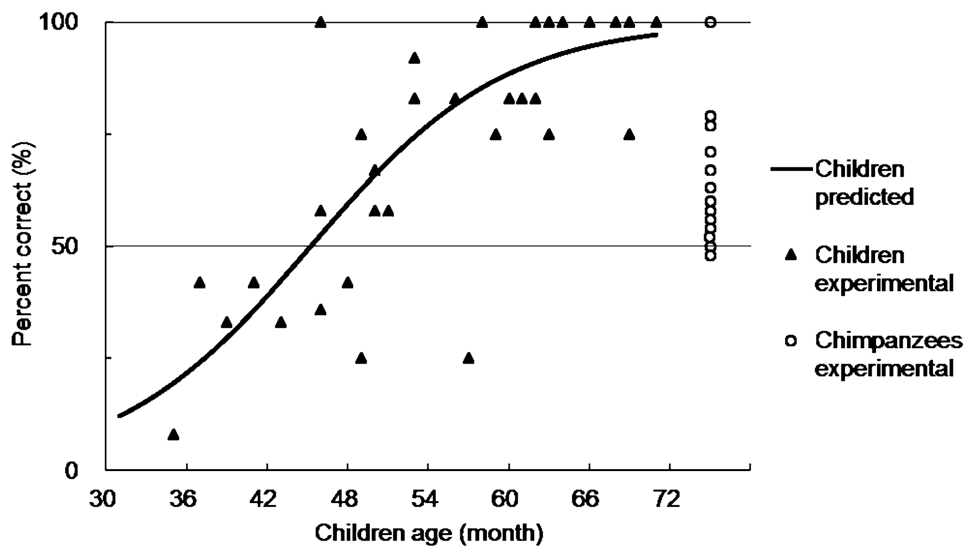


Fig. 5 Performances of children in the random sessions and of chimpanzees in the random test sessions prior to completing training. *Curve* Predicted accuracy of children's performances according to the logistic regression for age produced by the generalized linear mixed model analyses. *Triangles* Children's data from the experiment, *hollow circles* chimpanzee's pretest data

In the comparison between children and chimpanzees, in experiment 1, the seven chimpanzees were pretested with random sessions before they entered the random phase; the mean accuracy level was 66.00 ± 3.43%, similar to the predicted performances of children that were approximately 4 years old (Fig. 5). Therefore, the ability of the chimpanzees to perform the tasks in the random sessions appeared equal to that of children at 4 years of age, which is the critical time point for developing the ability to solve loop problems using configural methods.

Discussion

Chimpanzees

The present demonstration that chimpanzees were able to learn a circular relationship is consistent with the findings of Thompson (1953). The latter study included only preadolescent males, whereas the chimpanzees that completed the training in the present study (Table 1) included three older adult females (Ai, Chole, and Pendesa), one young adult female (Pal), and one young adult male (Ayumu); the two chimpanzees that did not complete the task were one older adult female (Pan) and one young adult female (Cleo). As Pan is Pal's mother, and Cleo is Chloe's daughter, family membership clearly did not have an effect. Based on these findings, differences in these chimpanzees' performances are unlikely to be age- or sex-related, and more likely to be due to individual differences.

The novel stimuli in the generalization tests were somewhat similar to the stimuli used in the training phase. However, the chimpanzees' performances during their first sessions with the first new stimuli, human hand 1, did not significantly differ from chance. Although the chimpanzees performed this test immediately after reaching the criterion in the training phase, it is conceivable that they did not perceive the two sets of stimuli as similar, in comparison to humans, who do. Chimpanzees' perception and visual acuity are comparable to those of humans (Matsuzawa 1990); however, the gestures included in the two stimulus sets of hands used in this study were slightly different, and it is possible that the similarity was not recognized by the chimpanzees. This leads to an interesting question regarding whether chimpanzees can recognize different types of body parts of a closely related species; therefore, it is important to be cautious about the effects of the perception of stimuli. Nevertheless, most of the chimpanzees ultimately reached the criterion with the new stimuli, indicating their ability to learn the circular relationship using various stimuli.

The learning pattern of the chimpanzees in the present study is consistent with those observed in rats and pigeons (Alvarado and Rudy 1992; Couvillon and Bitterman 1996; Wynne 1996). It is also consistent with Gillan's (1981) finding. Additionally, like chimpanzee Sadie, the participants in this study, especially Cleo and Pan, had difficulty in finalizing the circularity and took a long time to finish the single-pair sessions (Fig. 3). Moreover, all chimpanzees had difficulties finalizing the circularity, which could be explained by the content of the relationships (Alvarado and Rudy 1992; Couvillon and Bitterman 1996; Wynne 1996). Animals can complete the first two test pairs using elemental associations without configural associations, i.e., they can process paper, rock, and scissors as individual elements. However, with the third pair, the predefined right choice goes against the elemental association, and one needs to process paper–rock, rock–scissors, and scissors–paper in a configural manner to complete the transverse patterning task. This configural method of learning appears to be shared by rats, pigeons, and chimpanzees. It is possible that the chimpanzees, especially Cleo and Pan, were paying attention to the correct element only instead of paying attention to both elements within a pair, especially in the beginning. That they treated the task as a visual search task other than a discrimination task, in other words, that they focused on learning set formation (Harlow 1949, 1959), might have caused them difficulty in learning the three pairs. However, given their superior ability to memorize (Kawai and Matsuzawa 2000; Inoue and Matsuzawa 2007) and that they experienced hundreds of sessions, it is reasonable to suspect that eventually it was the lack of configural consideration that caused their difficulty in completing the task.

Children

In general, unlike the chimpanzees, the children exhibited little difficulty in learning this task. The children required an average of 5.83 trials for all three pairs, which suggests that they changed their choices immediately after a wrong choice because four consecutive successful trials were necessary to reach the criterion. Children were faster learners in this situation, showing few signs of difficulty as has also been reported in previous research (Carlozzi and Thomas 2008). One possible reason for this contrast is that in this study we kept the overall procedure the same as that used with chimpanzees, namely single-pair sessions first and then random sessions. This is different from the procedure used by Carlozzi and Thomas (2008), which consisted of one pair in phase 1, two pairs in phase 2, and three pairs in phase 3, a sequence which may have increased the difficulty of the task.

We found that the children's performance in the random sessions was age related, with better-than-chance performances in children older than 50 months. This finding is similar to that of Rudy et al. (1993), who reported that 4.5 years of age (54 months) is the critical time point for developing configural methods of problem solving.

Younger children performed below chance in the random sessions, which may be explained by the elemental way these children attempted to solve the problem. They did not perceive the pairs in a configural manner but perceived each element individually. For example, if they failed in a paper–rock trial by choosing rock, then they might have considered paper to always be correct and rock to always be incorrect. Thus, they would choose paper rather than rock in the next trial; if the next trial differed from the current trial, they would make the wrong choice again. That they completed the training sessions prior to the random sessions indicates that this circular problem is highly difficult for children below the critical age of approximately 4 years.

However, the results need to be treated with caution, because we cannot completely rule out the effect of familiarity. Older children might be more familiar with this game as they have more experience. Nevertheless, the experimental setting is different from the actual game. Younger children performed below chance in the mixed session, even after performing strongly in the single-pair phase. This suggests that they might not have fully understood the circular relationship in the rule, even though they knew the game and passed the training.

Chimpanzees versus children

The primary difference between the chimpanzees and children in the present study was the method of learning. Children changed their choice immediately after they made a wrong one, whereas the chimpanzees would often take multiple sessions to correct themselves. This difference may reflect that fact that children generally have better inhibitory control than chimpanzees (Herrmann et al. 2007; Vlamings et al. 2010). Additionally, inhibitory control typically makes great advances between 3 and 6 years of age (Gerstadt et al. 1994; Carlson and Moses 2001). Thus, it was easy for children to shift their choice immediately after a wrong trial, whereas it was difficult for chimpanzees to do so.

Although the overall procedures of the two experiments were similar, small details varied due to the different situations of chimpanzees and children. Therefore, one should be cautious when making comparisons between these two groups. Nevertheless, the parts of the test with the same content were chosen as the bases for comparisons. For the comparison of learning process, children changed their choices faster than chimpanzees. For the comparison of performance for the random condition, chimpanzees' pretests were done before they completed training, and the children's training procedure before the random test was relatively simple. Therefore, the random test situations were comparable across the two species.

The performances of the children under the random condition improved with age, but there was no significant effect of gender. Whether age and sex influence performance in chimpanzees remains unclear. In the study by Thompson (1953), four of five preadolescent males completed the transverse patterning task, whereas in the present study chimpanzees completing the task included both younger and older males and females.

In summary, the present study used a discriminative task based on the rules of the rock–paper–scissors game to systematically investigate whether chimpanzees could learn a circular relationship and to compare their learning with that of children. The chimpanzees were able to learn the circular relationship and generalize it to new stimuli.

However, they experienced difficulties finalizing the circularity. In contrast, children had little difficulty and required the same number of trials to complete all three pairs of tasks. However, children's performances under the random condition differed with age, and the predicted accuracy level of 67% fell at 50 months of age, which suggests that children acquire the ability to learn a circular relationship at approximately 4 years of age. Furthermore, the chimpanzees' performance in the random sessions prior to completing training was equal to that of 4-year-old children, as predicted from the data.

The present findings may inspire future studies to examine how age and sex influence the ability of members of various species to learn a circular relationship. Further studies should clarify the reasons for chimpanzees' and other animals' difficulties in learning circular relationships, including elemental/configural concepts and transitive/non-transitive inferences.

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Compliance with ethical standards

Author contributions J. G., Y. S., M. T., and T. M. designed the experiment; J. G., T. M., and M. T. collected the chimpanzee data; J. G. collected the child data; and J. G., Y. S., M. T., and T. M. wrote the manuscript.

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval The research proposal for the chimpanzees was approved by the Animal Welfare and Animal Care Committee of KUPRI and by the Animal Research Committee of Kyoto University (Nos. 2015-044, 2016-064). All procedures adhered to the Japanese Act on the Welfare and Management of Animals. The research proposal for the experiment with children was approved by the Human Research Ethics Committee of KUPRI (No. 2016-011).

References

Alvarado MC, Rudy JW (1992) Some properties of configural learning: an investigation of the transverse-patterning problem. J Exp Psychol Anim B 18:145–153

Astur RS, Sutherland RJ (1998) Configural learning in humans: the transverse patterning problem. Psychobiology 26:176–182

Bates D, Maechler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Softw 67:1–48. doi:10.18637/jss.v067.i01

Carlozzi NE, Thomas DG (2008) The utility of the transverse patterning task as a measure of configural learning in a college sample. Appl Neuropsychol 15:54–60

Carlson SM, Moses LJ (2001) Individual differences in inhibitory control and children's theory of mind. Child Dev 72:1032–1053

Couvillon PA, Bitterman ME (1996) Transverse patterning in pigeons. Anim Learn Behav 24:410–422

Gerstadt CL, Hong YJ, Diamond A (1994) The relationship between cognition and action: performance of children 3.5–7 years old on a Stroop-like day–night test. Cognition 53:129–153

Gillan DJ (1981) Reasoning in the chimpanzee. II. Transitive inference. J Exp Psychol Anim B 7:150–164

Gross WL, Greene AJ (2007) Analogical inference: the role of awareness in abstract learning. Memory 15:838–844

Harlow HF (1949) The formation of learning sets. Psychol Rev 56:51–65

Harlow HF (1959) Learning set and error factor theory. In: Koch SE (ed) Psychology: a study of a science, vol 2. McGraw-Hill, New York, pp 492–537

Herrmann E, Call J, Hernández-Lloreda MV, Hare B, Tomasello M (2007) Humans have evolved specialized skills of social cognition: the cultural intelligence hypothesis. Science 317:1360–1366

Hull CL (1943) Principles of behavior: an introduction to behavior theory. Appleton-Century-Crofts, New York

Inoue S, Matsuzawa T (2007) Working memory of numerals in chimpanzees. Curr Biol 17:R1004–R1005

Kawai N, Matsuzawa T (2000) Cognition: numerical memory span in a chimpanzee. Nature 403:39–40

Matsuzawa T (1990) Form perception and visual acuity in a chimpanzee. Folia Primatol 55:24–32

Matsuzawa T (2001) Primate origins of human cognition and behavior. Springer, Tokyo

Matsuzawa T (2003) The Ai project: historical and ecological contexts. Anim Cogn 6:199–211

Matsuzawa T, Tomonaga M, Tanaka M (2006) Development in chimpanzees. Springer, Tokyo

Nejime M, Inoue M, Saruwatari M, Mikami A, Nakamura K, Miyachi S (2015) Responses of monkey prefrontal neurons during the execution of transverse patterning. Behav Brain Res 278:293–302

Ochiai T, Matsuzawa T (1997) Planting trees in an outdoor compound of chimpanzees for an enriched environment. In: Hare VL, Worley KE (eds) Proceedings of the Third International Conference on Environmental Enrichment. The shape of enrichment. San Diego, pp 355–364

R Core Team (2016) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. URL https://www.R-project.org/. Accessed 26 June 2017

Rudy JW, Keith JR, Georgen K (1993) The effect of age on children's learning of problems that require a configural association solution. Dev Psychobiol 26:171–184

Spence KW (1952) The nature of the response in discrimination learning. Psychol Rev 59:89

Thompson R (1953) Approach–avoidance in an ambivalent object discrimination problem. J Exp Psychol 45:341

Tomonaga M (2001) Investigating visual perception and cognition in chimpanzees (*Pan troglodytes*) through visual search and related tasks: from basic to complex processes. In: Matsuzawa T (ed)

Primate origins of human cognition and behavior. Springer, Tokyo, pp 55–86
Vasconcelos M (2008) Transitive inference in non-human animals: an empirical and theoretical analysis. Behav Process 78:313–334
Vlamings PH, Hare B, Call J (2010) Reaching around barriers: the performance of the great apes and 3–5-year-old children. Anim Cogn 13:273–285
Wynne CDL (1996) Transverse patterning in pigeons. Behav Process 38:119–130