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Different Cognitive Strategies for Determining Common Image Features in Other Primates and Preschool Children

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Abstract
One of the stages in the formation of concepts is the identification of common object features or common image features (CIFs). Testing for differences in how humans and other primates identify CIFs is of scientific interest, because such differences can shed light on the cognitive strategies used during concept formations. We tested how 11 macaques (*Macaca mulatta*), two gibbons (*Hylobates lar*), and 41 children aged 4–5 years and 6–7 years to determine CIFs. The participants performed a sequence of tests containing nine tasks with different CIFs. Each task included a learning stage when participants had to identify a CIF and a testing stage when they had to categorize new stimuli corresponding to this CIF. The other primates took longer than children to identify CIFs during the first five tasks but then quickly identified new CIFs in the subsequent four tasks. In children, the time taken to identify CIFs did not depend on the place of a task in task sequence. They quickly identified some features (e.g., black or white), but other features (e.g., presence or absence of angles) took considerably more time. This difference was most likely related to the degree of familiarity of the image features. The ability to categorize was lower in the 4–5-year-old children than the older children, macaques, and gibbons. The different strategies used to identify CIFs may be linked to the prevalence of two functions of abstract thinking: the inductive function in other primates, and the deductive function in 4–5- and 6–7-year-old children.

Keywords Empirical concepts · Common image features · Macaques · Gibbons · Children

In everyday life, individuals must extract meaningful information from the environment to search successfully for resources to survive. Primates achieve this through a well-developed ability to form concepts (Christie, 2021; Smith et al., 2016;

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Thompson & Oden, 2000; Zental et al., 2008). Concept formation is a cognitive process that enables individuals to perceive the essential common features of objects by synthesizing a multitude of visual images forming in brain. This ability allows primates to minimize the trial-and-error phase in learning and plays an important role in organizing the fundamentals of intellect. “The sense of sameness is very keel and backbone of our thinking” (James, 2007, p. 459). Conceptual development is thought to progress from simple perceptual grouping to highly abstract scientific concepts (Sloutsky, 2010). Concepts are formed by the inductive function of abstract thinking through the synthesis of separate empirical representations (generalization). When a concept is formed, then a specific feature of an object can be attributed to this concept by using the deductive function of abstract thinking (categorization).

Empirical concepts can be based on: 1) generalization of representations of the specific features of an object (e.g., the concept of a “circle”); or 2) generalization of the relations among specific objects (for example, the concept of “more/less”). In addition, concepts can differ in the levels of generalization: 1) an elementary concept of a “circle” or a more general category of “geometric shapes”; 2) the elementary relative concept of “more/less” and a relative category of “same/different.” Studies of other primates showed that the rate of concept formation based on generalizing specific stimuli or simple relationships among stimuli (Golubeva & Kuznetsova, 2013; Malyukova et al., 1990; Tikhonravov et al., 2018) was much lower than the rate of the formation of relational categories, such as “same/different” (Fagot et al., 2001; Katz & Wright, 2021; Katz et al., 2002; Smith et al., 2010; Truppa et al., 2011). Some authors associate the main cognitive advantage of humans over other primates with a high level of understanding of relationships (Gentner, 2010; Penn et al., 2008).

Children develop a tendency to focus on objects during the first 2–3 years of life (Haun et al., 2006; Xu et al., 2005). As a result, they begin to focus more on the similarity between objects than on relational similarity. Subsequently, this preference facilitates higher levels of generalization, leading to relational abstractions. This is primarily due to an increased capacity for making distant comparisons (Gentner & Hoyos, 2017). Other primates, in contrast, are more focused on the relationship between objects. They are not distracted by matching the objects themselves and, unlike children, relational abstraction is easier for them when the objects are considerably different from each other (Christie, 2021; Christie et al., 2016).

Another view suggests that concept formation relies solely on the exploration of perceptual similarities in monkeys, unlike humans and apes (Flemming & Thompson, 2021; Thompson & Oden, 2000). Several studies have shown differences among adults, children, and other primates in the use of the local and global principles of grouping features when identifying objects (Hopkins & Washburn, 2002; Neiworth et al., 2006, 2014) and between human and other primates in the use of a multidimensional attention strategy based on finding common similarities (fast, intuitive, subconscious strategy) and a rule-based, analytical strategy (slow, conscious strategy) (Ashby & O'Brien, 2005; Couchman et al., 2010; Zakrzewski et al., 2018). Some researchers hypothesize that cognitive processes in the early development of children are grounded in powerful learning mechanisms, such as statistical and attentional learning (French et al., 2004; Sloutsky, 2010). From our point of view, those mechanisms most likely correspond to the trial-and-error method, which plays an important role in learning. The formation of concepts in infants when they are presented with animal images is essentially a bottom-up process (French et al., 2004). According to this view, category learning is achieved by detecting multiple shared characteristics or similarities among the presented objects.

There is a lack of data describing differences between other primates and children in their performance of tasks involving the formation or actualization of concepts, which rely on identifying common features among objects. We subjected macaques, gibbons, and children aged 4–5 years and 6–7 years to a series of tests involving generalization during a learning stage and categorization during a testing stage. We hypothesized that other primates and human children use different cognitive strategies to form concepts. If this is the case, then we predict that other primates and human children will differ in the rate at which they identify common image features (CIFs). We further hypothesized that the inductive function of abstract thinking is predominant in other primates, such that they go through a trial-and-error phase while attempting to complete each task. If this is the case, then we predicted that other primates would take less time to identify CIFs as the experiment progressed. In contrast, we hypothesized that the deductive function of abstract thinking prevails over the inductive function in children, such that prior knowledge and experience of concept formation play a crucial role in their ability to make accurate decisions in cognitive tasks. If it is true, then we predicted that the CIFs would vary in complexity for the children and the duration of learning will depend on the CIFs themselves.

Methods

Participants

We studied 11 rhesus macaques (*Macaca mulatta*, 4 females and 7 males), aged 3–16 years at the vivarium at the I.P. Pavlov Institute of Physiology, Russian Academy of Sciences (RAS), St. Petersburg, Russia. For experiments, we relocated six macaques from their home cages to six experimental cages, where they performed the tasks individually. These animals had previously participated in various experiments, including using a touchscreen monitor (Podvigina et al., 2020). The remaining five macaques lived alone and completed the tasks in their home cages. We considered these macaques experimentally naive. Due to the arrangement of their cages in the same room, there was no opportunity for the macaques to observe each other's work.

We also studied two male, white-handed gibbons (*Hylobates lar*) aged 4 and 7 years at Leningrad Zoo, St. Petersburg, Russia. These were two adolescent males living with their parents and another offspring. We conducted the experiments in the zoo in a designated compartment in a spacious indoor enclosure that housed five members of the gibbon group, including the two participants. The gibbon participants had the freedom to move around their indoor facilities while performing the tasks. They could interact with their group members during the intervals between the trials. The experimental panel and separate compartment were designed in a way that allowed only one gibbon to work at a time. The mean duration of a session for a nonhuman primate was 20 min.

We did not deprive the animals of food or water at any time. During the experiments, we used nuts and glazed sunflower seeds as rewards for the macaques and dates, prunes, raisins, and red pepper as rewards for the gibbons.

Finally, we studied 41 children (7 girls and 8 boys aged 4–5 years, and 14 girls and 12 boys aged 6–7 years) from kindergarten number 81, St. Petersburg, Russia. The children were all in the middle or preparatory groups of the kindergarten. Each child underwent testing individually in an experimental room. The mean duration of the session for a child was 20 min. We used attractive, paper stickers as rewards. We conducted the experiments from 2018 to 2020.

Ethical Note

We performed all experiments with rhesus monkeys in compliance with the protocol designed by the Animal Care Committee of the Pavlov Institute of Physiology, Russian Academy of Sciences (St. Petersburg, Russia). The protocol is based on the European Union Directive 86/609/EEC on the protection of animals used for experimental and other scientific purposes. We performed experiments with the white-handed gibbons in Leningrad Zoo according to the EAZA Code of Ethics 2015 (eazacodeofethics.pdf (earaza.ru)). We tested children in accordance with the ethical standards outlined in the Helsinki Declaration of the World Medical Association "Ethical principles for conducting scientific medical research involving a human being as a subject" as amended in 2013 (Helsinki Declaration, 1964), and the "Rules of Clinical Practice in the Russian Federation," approved by the 266th Order of the Ministry of Health of the Russian Federation on June 19, 2003. Parents gave written consent for their children to participant in the study.

Conflicts of interest/Competing interests The authors declare no conflict of interest, either existing or potential.

Experimental Set-Up

We used an experimental panel equipped with two holes spaced 15 cm apart. The experimental stimuli consisted of plastic cards (measuring 10 cm × 10 cm), each displaying a different image. We placed these cards over the holes (Fig. 1). For the macaques and gibbons, we fixed the cards to the panel by using two horizontal guides that allowed them to be moved either to the left or to the right, thus opening the holes.

Fig. 1 Study subjects performing tasks that involve identifying common image features. (**a**) Rhesus macaque (*Macaca mulatta*), Biocollection of Pavlov Institute of Physiology, Russian Academy of Sciences, (**b**) white-handed gibbon (*Hylobates lar*), Leningrad Zoo, (**c**) 4–5-year-old child, and (**d**) 6–7-year-old child. The children were at kindergarten number 81, St. Petersburg, Russia. We conducted experiments from 2018 to 2020.

Before commencing the experiment, we trained the macaques and gibbons to retrieve rewards from the holes in the experimental panel over 1–2 days. This training involved sliding aside white cards without any images.

Just before the study with children, the experimenter told the child, "I will show you two pictures. There will be a hidden treasure under one of them. Please, try to guess where the treasure is." If the child guessed correctly, the experimenter praised him/her, saying, "Well done! You have found the treasure! It's yours." If the child did not guess correctly, the experimenter reassured him/her, saying, "Don't be upset, please. You will find it next time."

During a trial, we placed two cards with different images to cover the holes. We positioned a reward underneath one of the cards. During the main experiment, we placed the experimental panel with two cards in front of the participants. The participants could move either of the cards. We recorded a correct response when a participant moved the card with an image with a particular feature to uncover the hole containing the reward. We did not reward incorrect responses. Then, we removed the panel. We prepared sets of stimuli in advance and manipulated the stimuli out of sight of the participants. We selected the side of the presentation of stimuli in a pseudo-randomized order, ensuring that the correct stimulus did not repeat on one side more than three times consecutively. If a participant left the experimental site and did not return within 5 min, we terminated the session for that day.

Stimuli

We employed a modified method to test for the differentiation of visual stimuli in humans and animals (Bongard, 1970). We presented participants with a total of nine tasks. Each set of nine tasks comprised 40 images (we used 20 images during the learning stage, and the remaining 20 images during the testing stage). In each trial, we presented a new pair of stimuli (ESM_1 provides examples of stimuli for four tasks, and examples of a 30-trial experimental session for CIF A task). The stimuli in each task were distinct from each other based on a unique image feature. To successfully complete a task and receive a reward, participants had to identify the CIF across the task. There were nine CIFs, one for each task (Fig. 2). During the learning stage, each stimulus image contained an outline figure (Fig. 2.1). In the testing stage, each stimulus showed four outline figures (Fig. 2.2; ESM_1). We did not arrange the CIF tasks based on their level of difficulty.

The learning stage played a crucial role in forming concepts based on identifying CIFs. The testing stage evaluated the ability to refer the concepts acquired based on one component to images based on four components.

Behavioral Paradigm

The participants performed nine tasks presented either in direct or reverse order. We presented the forward order (CIF A-I) to seven macaques, one gibbon, 11 children aged 4–5 years and 22 children aged 6–7 years. We presented the reverse order (CIF I-A) to four macaques, one gibbon, four children aged 4–5 years, and four children aged 6–7 years. We presented participants with one task per day. In each trial, we presented a new combination of stimuli for each task (ESM_1). All participants had to independently identify the CIF without any instructions from the experimenters. The only feedback was the presence or absence of reward. Due to the small number of white-handed gibbons, we did not counterbalance the rewarded CIFs in a pair of stimuli among participants.

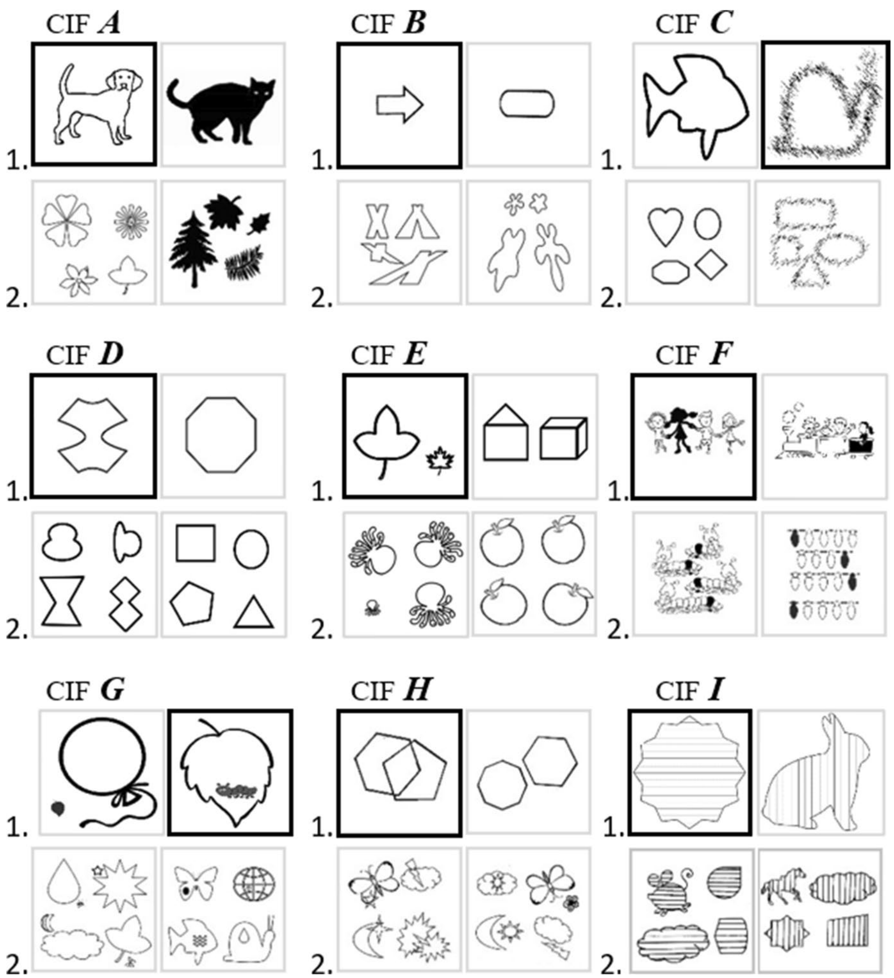

Fig. 2 Examples of one trial (image pair) for each of nine tasks used in (1) the learning stage and (2) the testing stage of an experiment to examine how macaques, gibbons, and humans identify common image features (CIFs). Visual stimuli in each task were distinct from each other based on a CIF: CIF A—black or white color; CIF B—presence or absence of angles; CIF C—smooth or toothed outline; CIF D—presence or absence of a constricted element or elements in the figure or figures; CIF E—presence or absence of a smaller element; CIF F—a black element at the end or in the middle of a chain or chains of images; CIF G—a smaller element inside or outside a larger one; CIF H—presence or absence of overlapping figures; CIF I—vertical or horizontal hatching. The rewarded CIF is framed.

During the learning stage, we required participants to identify CIFs to form concepts. We conducted the learning stage until all the participants reached an accuracy level of $\geq 75\%$ correct responses in a single session of 30 trials. If the participants achieved $\geq 75\%$ in the first session, we took this to mean that they identified the CIF quickly during the learning stage. If they took more than one session for a participant to reach $\geq 75\%$ accuracy, we took this to mean that a prolonged search occurred during the learning stage. If a participant did not complete the 30-trial session and refused to continue, we provided them with a 30-trial session on the following day. In some cases, when a participant almost reached the criterion but made a mistake toward the end of the session, we offered them five to ten additional trials. We included these additional trials in the analysis. If the participant continued to make mistakes even after the additional trials, we terminated the session for that day. In such cases, we provided the participant with a full-length session consisting of 30 trials on the following day. There were no restrictions on the number of trials in the learning stage.

Once a participant completed the learning stage for CIF A, we immediately administered the corresponding testing stage. During the testing stage, each task consisted of 30 trials. We used the same rewards during the learning stage and the testing stage. We considered the testing stage successful if a participant achieved an accuracy of $\geq$ 75% within the allotted 30 trials.

Variables and Statistical Analysis

We calculated the following variables for each group of participants: (i) percentage of participants who required either a quick or a prolonged search to identify the CIFs in each task; (ii) length of the learning stage, measured as the number of trials required to reach $>$ 75% correct responses in a single session of 30 trials; (iii) performance accuracy for each of the nine tasks in the testing stage (percentage of correct responses in 30 trials); (iv) transfer coefficient (TC), or the ability to transfer the concept acquired based on one component to images containing four components, calculated as (N/9) * 100, where N is the number of tasks in which the 75% level of performance was achieved, and nine is the total number of tasks.

We conducted statistical analysis by using GraphPad Instat and StatSoft Statistica 10.0 software. We set alpha at 5%. To test our prediction that other primates would take less time to identify CIFs as the experiment progressed, we examined the length of the learning stage and performance accuracy of the testing stage for gibbons and macaques in the first five and last four CIF tasks in both the direct and reverse order. To test our hypothesis about an important role of CIFs themselves in children, we examined the performance of both groups of children in tasks having a prolonged search (difficult tasks) and tasks having a quick search (simple tasks) presented in both the direct and reverse order.

If the data passed the normality distribution test, we used a one-way ANOVA with Tukey–Kramer post hoc tests to test for differences inside the same group (performance in first five vs. last four CIF tasks in other primates or performance in simple tasks vs. difficult tasks in both groups of children) and between the groups of participants (macaques vs. gibbons or 4–5-year-old children vs. 6–7-year-old children). In this case, the data are presented as mean $\pm$ standard error (SE). If the data did not pass the normality distribution test, we used a Kruskal–Wallis test with Dunn's post hoc test for the analogous comparisons. In this case, the data are presented as median and interquartile range.

To test our prediction about the different behavioral strategies to identify CIFs, we used two-way analysis of variance (ANOVA) with a group factor (nonhuman primates, 4–5-year-old children, 6–7-year-old children) and task type factor (first five vs. last four tasks) and a two-way ANOVA with the same group factor and a task type factor (simple tasks vs. difficult tasks). The dependent variable was the number of trials required to reach more than 75% of correct responses.

Results

Characteristics of CIF Determination in Other Primates and Children

During the learning stage, all the macaques and gibbons successfully identified the CIF for each task. The 75% performance level was achieved within one session (30 trials) for some tasks, whereas more than 30 trials were needed to reach the same level for other tasks. All 11 macaques needed extended search periods to identify the CIF in the first task (CIF A task for the direct order and CIF I task for the reverse order) (Fig. 3a). Nine macaques (82%) showed a prolonged search during the second task (CIF B or CIF H). However, for the subsequent three tasks (CIF C-E forward/ CIF G-E reverse), only five or six animals (45–55%) required more than 30 trials to solve the task successfully. Except for one individual who required additional trials to meet the criterion during the CIF G task (Fig. 3a), all macaques completed the last four CIF tasks within the allocated 30 trials. We observed a similar pattern in

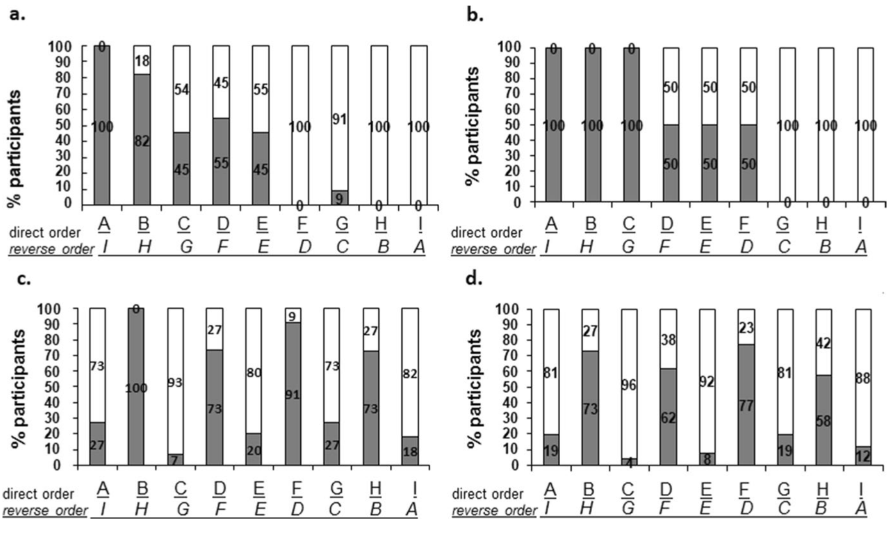

Fig. 3 Percentage of participants in four groups: macaques (**a**); gibbons (**b**); 4–5-year-old children (**c**); 6–7-year-old children (**d**), performing a series of tasks in direct or reverse order (CIFs A-I or CIFs I-A) with a prolonged search (grey fill) or a quick search (no fill). We studied rhesus macaques (*Macaca mulatta*) at the I.P. Pavlov Institute of Physiology of the Russian Academy of Sciences, white-handed gibbons (*Hylobates lar*) in Leningrad Zoo, and children in kindergarten number 81, St. Petersburg, Russia. We conducted the experiments from 2018 to 2020.

gibbons (Fig. 3b). While one gibbon required extra time for the first three CIF tasks, another one needed more time to perform the first six CIF tasks correctly. One gibbon searched for the CIFs for the last six tasks quickly, and the second did so for the last three CIF tasks (Fig. 3b).

All children in both age groups identified the CIF for each task, but their working pattern differed from that in the other primates. During the learning stage, a majority of children aged 4–5 years (11–15 participants, 73–100%) and 6–7-years (15–20 participants, 58–77%) showed a prolonged search in tasks 2 (CIF B/H), 4 (CIF D/F), 6 (CIF F/D), and 8 (CIF H/B) (Fig. 3c, d). We considered these tasks difficult. In contrast, a majority of children aged 4–5 years (11–14 participants, 73–93%) and 6–7 years (21–25 participants, 83–96%) determined CIFs quickly in tasks 1 (CIF A/I), 3 (CIF C/G), 5 (CIF E), 7 (CIF G/C), and 9 (CIF I/A) during the learning stage (Fig. 3c, d). We considered these tasks simple.

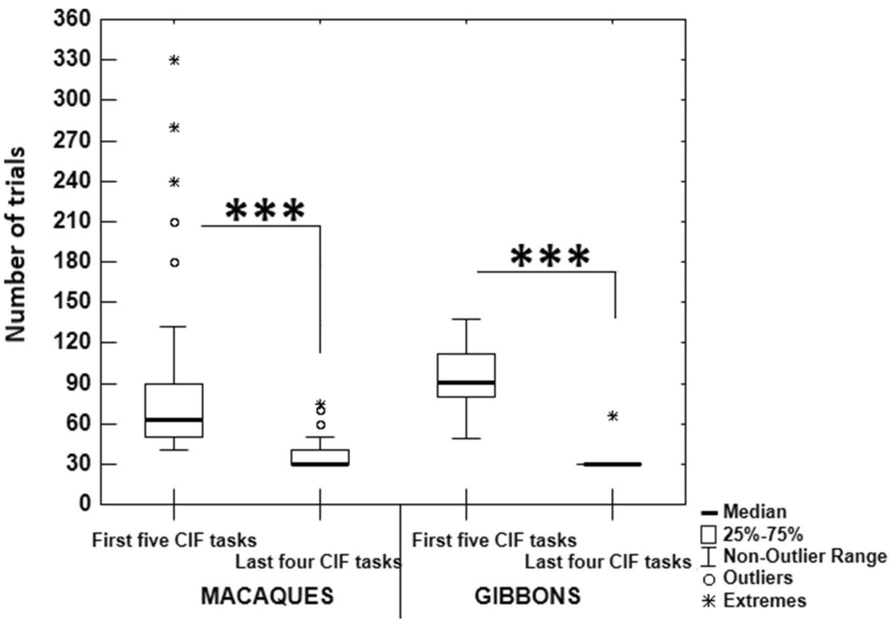

Fig. 4 Length of the learning stage, measured as the number of trials required to reach > 75% correct responses in the first five and last four of nine common image feature (CIF) tasks in macaques and gibbons. Kruskal–Wallis test: H (3, 117) = 66.55, $P < 0.001$ with Dunn's post hoc test to test differences in first five vs. last four CIF tasks in macaques and gibbons as well as between the groups of primates (macaques vs. gibbons). Significant differences are shown as ***$P < 0.001$. We studied rhesus macaques (*Macaca mulatta*) in I.P. Pavlov Institute of Physiology of the Russian Academy of Sciences and white-handed gibbons (*Hylobates lar*) in Leningrad Zoo, St. Petersburg, Russia. We conducted experiments from 2018 to 2020.

Learning Stage in Nonhuman Primates

On average, macaques needed two sessions (median = 63 trials, quartile = 40) to achieve the 75% criterion in the first five tasks. Gibbons needed three sessions (median = 90 trials, quartile = 32). However, these primates completed the last four tasks within the first session (median = 30 trials, quartile = 10 for macaques, and quartile = 0 for gibbons). The number of trials required to reach 75% correct performance at the learning stage was significantly different between tasks 1–5 and tasks 6–9, regardless of the order (forward or reverse) (Fig. 4). We observed this pattern in both presentation orders. The number of trials required to achieve 75% correct task performance in the first five CIF tasks did not differ statistically between macaques and gibbons (Dunn's post hoc test: $P = 0.10$). Similarly, the number of trials required to achieve the 75% level of correct performance in the last four tasks did not differ statistically between the species (Dunn's post hoc test: $P = 0.24$, Fig. 4). Individual data on the number of trials required to achieve 75% criterion in one session for each of the nine tasks and for each subject are presented in the Electronic Supplementary Material (ESM_2).

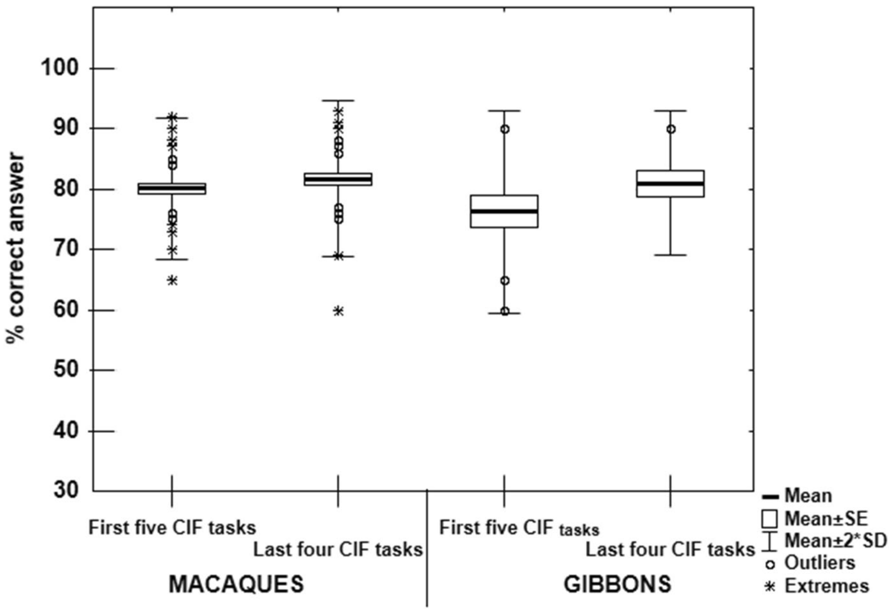

Fig. 5 Accuracy of performance of tasks at the testing stage in the first five and last four common image feature tasks in two species of primate. One-way ANOVA: $F(3, 113) = 2.18$, $P = 0.09$ with Tukey–Kramer post hoc tests to test differences in first five vs. last four CIF tasks in macaques and gibbons as well as between the groups of primates (macaques vs. gibbons). We studied rhesus macaques (*Macaca mulatta*) at the I.P. Pavlov Institute of Physiology of the Russian Academy of Sciences, white-handed gibbons (*Hylobates lar*) in Leningrad Zoo, St. Petersburg, Russia. We conducted experiments from 2018 to 2020.

Testing Stage in Nonhuman Primates

All the macaques and gibbons successfully completed the learning stage and the test for each of the nine tasks. The individual data on the percentage of correct answers for 30 trials for each of the nine tasks, and each subject is presented in the Electronic Supplementary Material (ESM_3). We found no significant differences between the accuracy of task performance in the first five and last four tasks in either macaques or gibbons or between the task performance of macaques and gibbons (Fig. 5).

Learning Stage in Children

On average, children reached the 75% criterion in the first session during simple tasks (median = 30 trials, quartile = 10 in 4–5-year-old children and quartile = 0 in 6–7-year-old children). However, during difficult tasks, 4–5-year-old children required almost three sessions (median = 76 trials, quartile = 47) to reach the 75% criterion and 6–7-year-old children also needed additional trials (median = 40

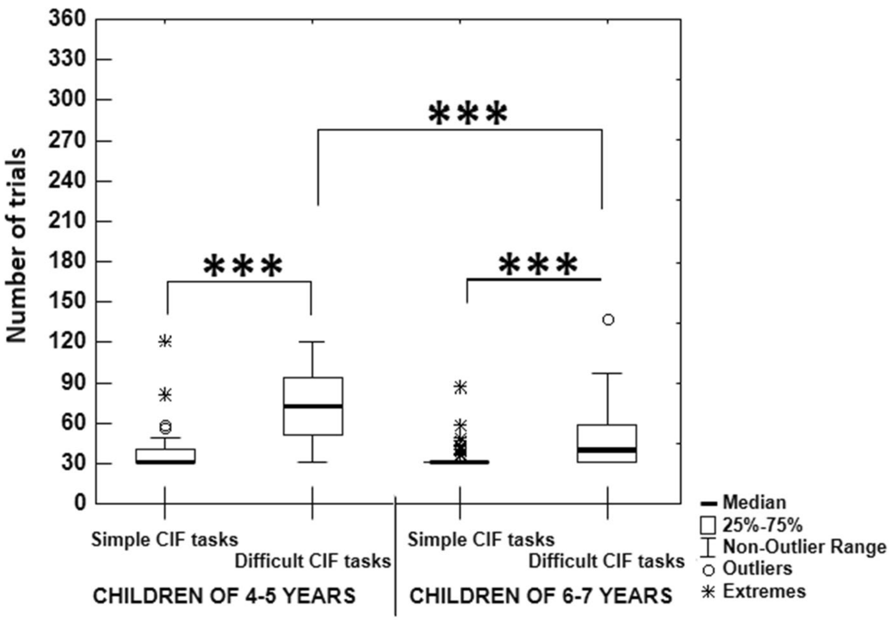

Fig. 6 Length of the learning stage, measured as the number of trials required to reach > 75% correct responses in simple (A, C, E, G, and I) and difficult (B, D, F, and H) common image feature tasks in 4–5-year-old children and 6–7-year-old children. Kruskal–Wallis test: H(3, 358) = 142.66, $P < 0.001$ with Dunn's post hoc test to test differences in simple tasks vs. difficult tasks in both groups of children as well as between the groups of children (4–5-year-old children vs. 6–7-year-old children). Significant differences are shown as ***$P < 0.001$. We studied children in kindergarten number 81, St. Petersburg, Russia from 2018 to 2020.

trials, quartile = 30) to achieve the same criterion. The number of trials required to achieve 75% correct at the learning stage to complete simple tasks was significantly lower than for difficult tasks in both age groups (Fig. 6). We observed this pattern in both presentation orders. The number of trials to complete the simple tasks did not differ significantly between age groups (Fig. 6). However, the number of trials while performing the difficult tasks was significantly higher in the 4–5-year-old children than in the 6–7-year-old children (Fig. 6). Individual data on the number of trials required to achieve the 75% criterion in one session for each of the nine tasks and for each subject are presented in the Electronic Supplementary Material (ESM_2).

Testing Stage in Children

All children successfully completed the learning stage and completed the test for each task. The individual data on the accuracy of test (% correct answers for 30 trials) for each of the nine tasks and for each subject are presented in the Electronic Supplementary Material (ESM_3). Success was significantly lower in the testing stage for difficult tasks than for simple tasks (Fig. 7). The accuracy in simple and

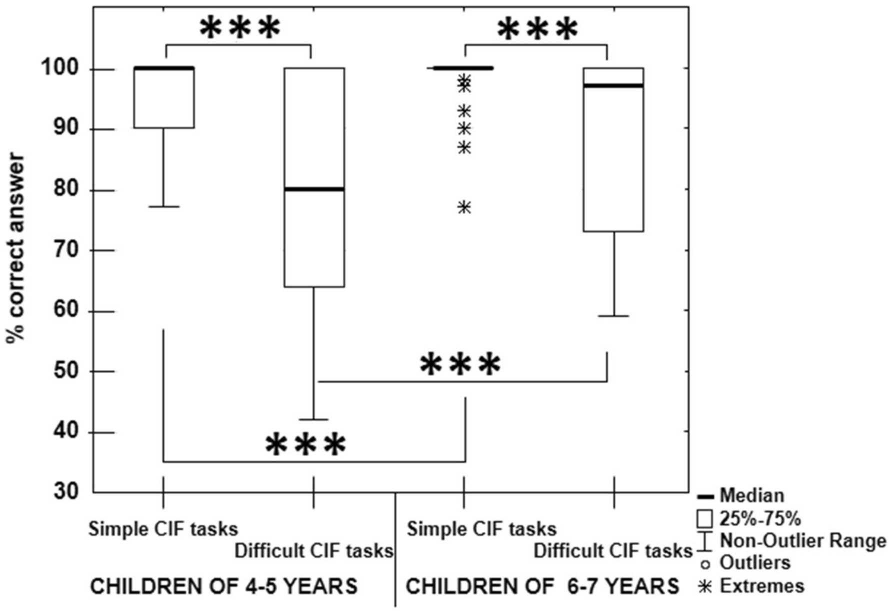

Fig. 7 Accuracy of the performance of simple and difficult common image feature (CIF) tasks in 4–5-year-old children and 6–7-year-old children at the testing stage. Kruskal–Wallis test: H (3, 359) = 67.94, P < 0.001 with Dunn's post hoc test to test differences in simple tasks vs. difficult tasks in both groups of children as well as between the groups of children (4–5-year-old children vs. 6–7-year-old children). Significant differences are shown as ***$P < 0.001$. We studied children in kindergarten number 81, St. Petersburg, Russia, from 2018 to 2020.

difficult tasks in children 4–5 years old was significantly lower than that in children 6–7 years old (Fig. 7).

Comparison of Nonhuman Primates and Children

We combined the macaques and gibbons into a single group of nonhuman primates, because the length of the learning stage and accuracy of the performance testing tasks in did not significantly differ between species (Figs. 4, 5). We had to analyze the two age groups of children separately, because significant differences were between 4–5-year-old children and 6–7-year-old children (Figs. 6, 7).

We found a significant interaction between the group (nonhuman primates, 4–5-year-old children, 6–7-year-old children) and the task type (first five vs. last four tasks) (two-way ANOVA $F(2, 102) = 18.44$, $P < 0.001$; Fig. 8a). In nonhuman primates, there was a significant decrease in the time taken to identify CIFs in the last four tasks compared with that in the first five tasks (Tukey–Kramer post hoc test: $P < 0.001$). However, we did not observe such differences in the children (4–5-year-old children: $P = 0.87$; 6–7-year-old children: $P = 0.99$, Tukey–Kramer post hoc test). Moreover, the nonhuman primates took significantly longer to identify CIFs in the first five tasks than both groups of children groups (Tukey–Kramer post hoc test: $P < 0.001$ in both cases). However, nonhuman primates solved the last four tasks faster than 4–5-year-old children (Tukey–Kramer post hoc test, $P < 0.01$). We found no significant difference in the rate of identifying the last four CIFs between nonhuman primates and 6–7-year-old children (Tukey–Kramer post hoc test: $P = 0.99$).

We found a significant effect of the interaction of group (nonhuman primates, 4–5-year-old children, 6–7-year-old children) and task type (simple/difficult tasks) (two-way ANOVA: $F(2, 102) = 16.13$, $P < 0.001$, Fig. 8b). At the same time, we found no significant differences in the time taken to identify simple and difficult CIFs in nonhuman primates (Tukey–Kramer post hoc test, $P = 0.06$). However, there was a significant increase in the time taken for difficult CIFs compared with simple CIFs in both groups of children (4–5-year-old children, $P < 0.001$; 6–7-year-old children, $P < 0.05$, Tukey–Kramer post hoc test). Nonhuman primates also took significantly longer to identify simple CIFs than both groups of children (Tukey–Kramer

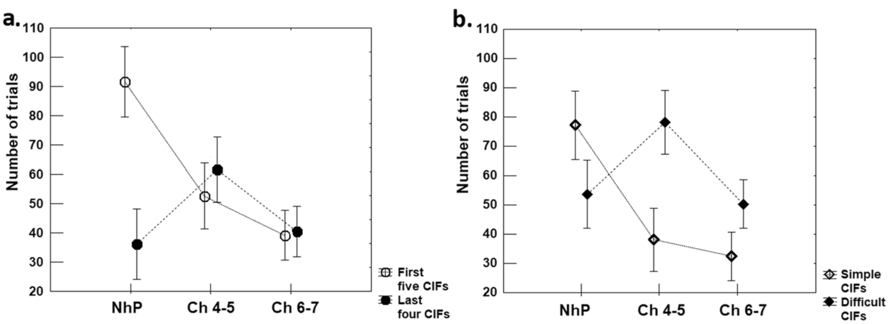

Fig. 8 The interaction of group and task type factors in nonhuman primates' (**a**) and children's (**b**) cognitive strategies for identification of common image features. Y-axis: mean ± 95% CI trial number.

post hoc test, $P<0.001$ and $P<0.001$, respectively). There were no significant differences in the time taken to identify simple CIFs between children in the two age groups (Tukey–Kramer post hoc test, $P=0.96$). The nonhuman primates identified difficult CIFs significantly faster than 4–5-year-old children (Tukey–Kramer post hoc test, $P<0.05$), but we found no significant differences in the time taken to identify difficult CIFs between the nonhuman primates and 6–7-year-old children (Tukey–Kramer post hoc test, $P=0.99$). In addition, we found significant differences in the time taken to identify difficult CIFs between the two groups of children (Tukey–Kramer post hoc test, $P<0.01$).

The mean TC was $84.0\pm0.1\%$ for nonhuman primates, $65.0\pm0.1\%$ for 4–5-year-old children, and $86.0\pm0.1\%$ for 6–7-year-old children. The TC in children aged 4–5 years was significantly lower than in nonhuman primates and older children (Fig. 9). The TC in nonhuman primates and children aged 6–7 years did not differ significantly from each other (Fig. 9).

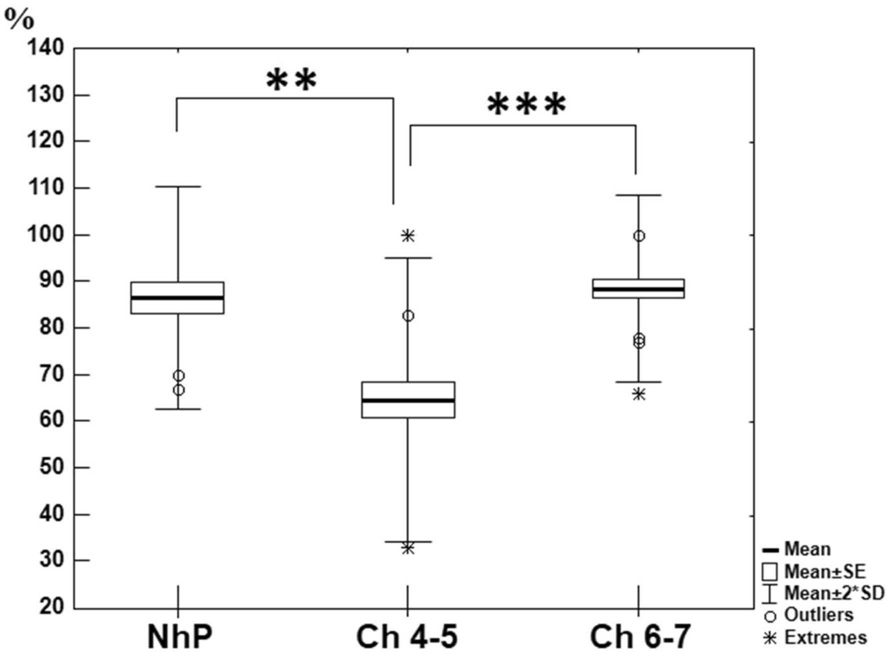

Fig. 9 Percentage of tasks performed successfully at the testing stage for all nine tasks in nonhuman primates, 4–5- and 6–7-year-old children. One-way ANOVA comparing groups: $F(2,50)=11.23$, $P<0.001$. $**P<0.01$ and $***P<0.001$ based on Tukey–Kramer post hoc tests.

Discussion

Our data suggest the presence of different strategies in others primates and children performing a series of tasks related to the identification of CIFs. Macaques, gibbons, and children could identify all the CIFs. However, it took them more time to identify some CIFs than others. Both macaques and gibbons required a prolonged search to identify CIFs in the first five tasks and then showed a quick search in the last four CIF tasks. There were no significant differences in the accuracy of task performance between the first five tasks and the last four tasks. Children identified some CIFs quickly, while they had a prolonged search for other CIFs. So, for the children, the tasks themselves varied in difficulty; there were simple and difficult tasks. In addition, the accuracy of performance differed significantly between simple and difficult tasks in older and particularly in younger children at the testing stage. We observed these patterns in both the direct (CIF A-I) and reverse (CIF I-A) task presentation orders.

Learning Stage

Nonhuman Primates

The performance of macaques and gibbons shared some common features. Both species took longer to identify CIFs in the first five to six tasks and then identified them very quickly in the following tasks, regardless of presentation order. This general tendency has been described as "cognitive mediation" (Harlow, 1949), "learning to learn" or "learning set formation" (Rumbaugh & McCormack, 1967), "abstract concept learning" (Wright & Katz, 2007), and "cognitive priming" (Falikman & Pechenkova, 2016). Obtaining and implementing the "task context" and "rules" to control behavior is the primary function of the prefrontal cortex (Asaad et al., 2000). Thus, the macaques and gibbons not only learned to identify specific CIFs for each of the nine tasks but also learned to look for CIFs, which allowed them to find correct solutions more quickly in later tasks. The results that we obtained in macaques are in line with their ability to solve subsequent tasks with fewer trials (Forbes & King, 1982; Kuznetsova & Golubeva, 2014). In our study, the duration of the learning stage did not differ between macaques and gibbons. This is contrary to the point of view that gibbons cannot form a training set and lack flexibility in their learning (Rumbaugh & McCormack, 1967; D'Agostino & Cunningham, 2015). Despite their well-developed neocortex, the cognitive abilities of gibbons have been traditionally considered as poor, although data on this subject are insufficient to draw strong conclusions (Cunningham & Mootnick, 2009). In some studies, gibbons have shown abilities comparable to those of great apes, for example, in using cloths and leaves as sponges (Tingpalapong et al., 1981) and understanding the relationships among three presented objects (a rake, a reward, and a trap) (Cunningham et al., 2006).

In the initial stages of the experiment, it took 60–90 trials for the nonhuman primates to reach the criterion for successful CIF identification. Previous experiments with real object stimuli have shown that gibbons could successfully perform color-reward associations in fewer than 100 trials (D'Agostino & Cunningham, 2015). In a study of rhesus macaques, they required up to 150 trials to reach 75% correct answers in matching-to-sample tasks presented as real objects and their images (Golubeva & Kuznetsova, 2013). To reach 70% correct answers, rhesus macaques required 66 trials to form the concept of "size" and 24 trials to form the concept of "shape" in tasks in which real geometric figures were presented (Tikhonravov et al., 2018). Identifying the dominant visual orientation of stimuli presented on a touchscreen required 100–400 trials (Podvigina et al., 2020). However, in a categorization task involving sine-wave gratings, rhesus macaques required more than 2,000 trials to reach the 70% level of correct answers. This task was designed to assess the macaques' ability to categorize gratings based on variations in bar width and bar orientation (Smith et al., 2010). In a "same/different" task, macaques reached 80% correct performance within 4000 trials, although the number of trials decreased as the size of the training set of stimuli increased (Katz et al., 2002). In these two studies (Katz et al., 2002; Smith et al., 2010), macaques were required to categorize individual objects into one of two concepts that had not been previously formed before the task. Any categorization performed by the deductive function of abstract thinking is performed after the concept formation (generalization) by using the inductive function of abstract thinking (Guyer & Wood, 1998). The large number of trials in these studies could be attributed to the requirement to categorize a stimulus at once without any prior concept formation at the generalization stage.

Under the conditions of our experiment, nonhuman primates first formed concepts based on the CIFs. The stimuli themselves physically blocked the rewards. This required the participants to make physical contact with the stimuli to search for and access the rewards. That contact also could help them to focus on the characteristics of the selected image and provide feedback for quick learning. Moreover, training monkeys to touch stimuli before making choices in a "same/different" task appears to have a positive impact on their performance accuracy (Katz et al., 2002).

In our experiments, both macaques and gibbons were highly motivated. However, macaques and gibbons showed important behavioral differences during the performance of tasks. While macaques were focused on finding reward during solving the task, the gibbons used the tasks for their own social purposes. The two adolescent, male gibbons participating in the experiments were from the same group and usually approached the experimental location one after another. Sometimes, their mother would come with a small baby in her arms and study the experimental set up. Occasionally, she moved cards to the right or left to get the reward, but she did not really participate in our experiments. Their father also visited the experimental compartment but did not approach the experimental set up closely. At the beginning of the experiment, the elder brother Orpheus dominated. He was more successful and quickly found solutions. The adolescents began to compete with each other in performing the tasks. The younger brother Theseus often stole the reward from his older brother if Orpheus answered correctly. When he failed a task, Theseus cried, rolled hysterically on the floor, and called on his parents who drove the elder brother Orpheus away. So, Theseus used the experimental situation to consolidate his hierarchical position and receive rewards. Because games with his mother and younger sister distracted Theseus from our experiments, we managed to complete our work with Orpheus. Our study shows that gibbons in a zoo with free access to the experimental set-up could perform quite difficult cognitive tasks.

Children

Unlike in the other primates, children's performance was the same in the first and second half of the series of tasks. In most children, we only observed a prolonged search period when they performed tasks with difficult CIFs presented in either order. It is possible that the children had already formed certain concepts and had experience in using them before the beginning of our experiment. Children in the kindergarten often engage in activities, such as coloring (the concept of black or white colors—CIF A), hatching (vertical or horizontal hatching—CIF I), drawing outlines (smooth or toothed outlines—CIF C), sorting and laying out toys (the presence or absence of a small element—CIF E and when a small element is placed inside or outside a larger one—CIF G). The familiar CIFs in these simple tasks likely corresponded to well-known empirical concepts that children have already acquired. In this case, the deductive function of abstract thinking (categorization) played the main role.

When children of both age groups performed difficult tasks, they needed to form new concepts. To do this, they had to find a difference in each pair of presented stimuli and identify CIF for all consecutively presented pairs of stimuli in the task. The representations based on those CIFs were probably synthesized by the inductive function of abstract thinking to form the corresponding concepts. The same CIFs appeared to be difficult for both age groups. However, the percentage of participants who had a prolonged search for the difficult tasks was lower in children aged 6–7 years than in the younger, and the rate of determining difficult CIFs was significantly higher in the older children than the younger children. As children grow older, there is a gradual shift from concrete to abstract thinking (Perlmutter et al., 1981; Piaget, 1999) and a shift toward relational processing driven by their increasing relational knowledge, processing productivity, and executive abilities, including inhibitory control (Gentner & Namy, 1999). By comparing the task performance in our experimental paradigm, we observed qualitative differences in the ability of nonhuman primates and children to identify CIFs and form generalized empirical concepts.

Testing Stage

The accuracy of task performance did not differ significantly between the macaques and gibbons and was approximately 80%. In addition, in both macaques and gibbons, there were no significant differences in the accuracy of task performance between the first five test tasks and the last four tasks, unlike during the learning stage. This finding shows that they were able to categorize new stimuli based on the concepts that they had formed during the learning stage.

The accuracy of performance differed significantly between simple and difficult tasks in older and particularly in younger children at the testing stage. The findings suggest that the presentation of the new stimuli in the difficult tasks posed challenges for both groups of children. On average, older children showed higher accuracy in both simple and difficult tasks than younger children. The 6–7-year-old children typically to assigned names of well-known objects or their properties to the stimuli. For example, they called the stimuli with angles “stars” or “sharp,” stimuli without angles “soft” and stimuli with constrictions as “pumpkins.” This is in line with the idea (Gentner & Hoyos, 2017) that analogical comparison is a major driver of children’s early cognitive development particularly in the formation of new relational abstractions.

General Discussion

Our data suggest that macaques and gibbons used the “trial and error” method in their search for the reward in the first five to six tasks. The experience gained during the initial learning stage allowed the primates to understand the principle for identifying CIFs and then use this principle to identify and determine the other CIFs quickly in the last three to four tasks. So, on average, the nonhuman primates required approximately five tasks to consolidate their experience. In contrast, children used previous knowledge to quickly achieve success in simple tasks. However, they lacked such knowledge during more difficult tasks and probably used “trial and error” or tested various hypotheses when looking for CIFs.

The number of trials at the learning stage revealed two different cognitive strategies for nonhuman primates and children. Unlike other primates, in children, there were no significant differences in the speed at which they identified the first five and last four CIFs. Unlike children, nonhuman primates did not show differences in the rate of identifying the simple and difficult CIFs. The inference of different cognitive strategies for identifying CIFs in nonhuman primates and children suggests qualitative differences in their ability to identify CIFs underlying formation of generalized empirical concepts.

Our findings align with existing data on the differences between nonhuman primates and humans, which are connected with the local and global principles of grouping features they employ during object identification (Hopkins & Washburn, 2002; Neiworth et al., 2014). The findings also align with the distinction between subconscious passive learning and analytical conscious learning methods of grouping objects into categories based on using multidimensional attention and forming rules (Couchman et al., 2010; Zakrzewski et al., 2018). The lack of the global precedence in processing difficult stimuli in the nonhuman primates suggests that their attention may be more focused on local features while children’s attention is more focused on global features, so they did not notice the particular features. The predominance of passive (subconscious) learning and the strategy of widespread attention to multiple aspects of stimuli in nonhuman primates could contribute to their ability to identify repeated differences in pairs of simultaneously presented stimuli leading to the identification of CIF and ultimately the formation of concepts. The analytical (conscious) strategy, based on one-dimensional criteria, allowed children to quickly notice familiar parameters or features of a stimulus and indefinity the simple CIF. At the same time, paying attention to the diversity of stimuli and following the tendency to evaluate global features of objects, children probably had some difficulty in identifying unfamiliar CIFs.

We can assume that the categorization of new images to existing corresponding concepts is simpler and faster than the formation of new concepts in children. However, the diversity of stimuli can result in incorrect hypotheses and challenges in identifying CIFs. Too few or too many differences between objects weakens the human abstraction of relationships, whereas in animals, relational abstraction is easier when the underlying objects are dissimilar (Christie, 2021). Similar effects have been observed in studies using the "same–different" paradigm in macaques (Katz et al., 2002; Smith et al., 2010).

Humans possess intuitions of geometry, but baboons appear not to (Sablé-Meyer et al., 2021). The authors proposed that these two species use correspondingly different strategies. They suggested that baboons predominantly rely on a perceptual strategy, in which geometric shapes are encoded using feature space. Humans primarily employ a symbolic strategy, in which geometric shapes are encoded by their discrete nonrandom patterns, in other words, rules. Our study shares some conceptual similarities with this earlier study. We explain the two strategies observed in nonhuman primates and children by the predominance of different cognitive processes. In nonhuman primates, the inductive function of abstract thinking appears to be predominant (bottom-up process, the formation of concepts through the generalization perceptual representations). In children, the deductive function of abstract thinking seems to be more prominent (top-down processing, searching the rules). This conceptual similarity is interesting because the two studies used different approaches. Baboons, unlike humans, could not transfer the understanding of the intruder task when using images of similar quadrilaterals instead of non-geometric images, while, in our work, macaques and gibbons could identify all the features studied, including those associated with geometry, for example, presence/absence of corners (CIF B). This might have been the result of the following methodological differences: 1) the number of simultaneously presented stimuli: two in our work and three to six in the work of Sablé-Meyer et al. (2021); 2) the use of card stimuli that are pushed aside to take a reward in our work versus virtual images on a monitor in the work of Sablé-Meyer et al. (2021). We consider that it was more challenging for baboons to find a stimulus that was different from the others when using six stimuli at the same time. In addition, virtual objects on the monitor screen are not natural for animals and require a lot of training.

Analysis of the transfer coefficient, which serves as an indicator of categorization ability, shows that nonhuman primates successfully categorized new stimuli based on concepts formed during the previous learning stage. The transfer coefficient observed in nonhuman primates was comparable to that in the older children and significantly higher than in the younger children. It seems that nonhuman primates primarily relied on the inductive function of abstract thinking (generalization) to identify CIFs and form new concepts. Moreover, nonhuman primates used their accumulated knowledge to establish general principles, enabling them to form new concepts more rapidly through the application of deductive function of abstract thinking.

In children, it is likely that the deductive function of abstract thinking starts to dominate over the inductive function, and this dominance increases as they continue to mature. The presence of numerous symbolic representations in children, along with their attempts to establish relational connections between stimuli based on their existing concepts, may have made it more challenging for them to identify CIFs in some difficult tasks. We hypothesize that attention of children might have been more focused on their own knowledge rather than on the specific features of the presented images. As such, while monkeys had to acquire new knowledge and experience during the experiments, children possessed their own knowledge and attempted to apply it in determining the CIFs, although these attempts were not always very successful.

One limitation of this study is that we did not counterbalance the rewarded CIF within a pair of stimuli across the participants. For example, in CIF A task, we rewarded all participants for choosing only white images but not black ones. This was because we studied only two gibbons. Because our main interest was the ability to search for specific features within the task sequence, rather than the features themselves, we deemed it more important to counterbalance the nine-task sequence with the different CIFs. However, another limitation of our study is that the direct and reverse order groups were not evenly balanced in terms of size. Increasing the number of participants to achieve a better balance between the direct and reverse order groups would be beneficial and would allow more accurate detection and generalization of different options for rewarded CIFs. For example, one group of participants could be rewarded for selecting white images, whereas the other group could be rewarded for selecting black images.

Conclusions

In macaques and gibbons, the number of trials to identify common image features (CIFs) depended on the experience gained by the animals during the completion of the first several tasks in a series: the first five CIF tasks required more trials compared with the last four tasks in both orders. In children aged 4–5 and 6–7 years old, the number of trials to identify CIFs depended on the complexity of CIFs themselves: children identified simple CIFs quickly and difficult CIFs slowly. CIF determination could be linked to the prevalence of one of the two functions of abstract thinking: the inductive function for nonhuman primates and deductive function for 4–5- and 6–7-year-old children.

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Authors' Contributions IG performed the research, analysis and interpretation of the data obtained, as well as wrote the manuscript. DT analyzed and interpreted the data obtained, as well as performed writing and translating the manuscript into English. TK performed the research and proofreading of the manuscript. All authors read and approved the final manuscript.

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Data Availability All the data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Inclusion and Diversity Statement One or more of the authors of this paper self-identifies as an underrepresented ethnic minority in science.

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