Unique numerical competence of Asian elephants on the relative numerosity judgment task

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Abstract

Many animals demonstrate numerical competence even without language. However, their representation is mainly based on inaccurate quantity instead of absolute numbers. Thus, their performance on numerical tasks is affected by the distance, magnitude, and the ratio of comparisons (i.e., as distance decreases, magnitudes increase, or as ratios increase the accuracy of discrimination decreases). We report that Asian elephants' numerical representation is quite different from that of other animals. We trained three Asian elephants to use a touch-panel apparatus and one female successfully learned to use the apparatus. Next, a relative numerosity judgment task was presented on the screen and the elephant was asked to touch, with the tip of her trunk, the figures with the larger numbers of items. The numbers of items in each figure ranged from 0 to 10. We found that her performance was unaffected by distance, magnitude, or the ratios of the presented numerosities but, consistent with observations of human counting, she required a longer time to respond to comparisons with smaller distances. This study provides the first experimental evidence that nonhuman animals have cognitive characteristics partially identical to human counting.

Keywords Numerical competence · Relative numerosity judgment · Asian elephants

Introduction

Even though nonhuman animals do not have language abilities, there is increasing evidence that they understand numerical representation (orangutans: Call 2000; chimpanzees: Beran 2001; Biro and Matsuzawa 2001; Murofushi 1997; Perusse and Rumbaugh 1990; Rumbaugh et al. 1987; Tomonaga 2008; gorillas: Anderson et al. 2007; rhesus monkeys: Beran 2007; Hicks 1956; bears: Vonk and Beran 2012; fish: Agrillo and Bisazza 2018; for a review, see Butterworth et al. 2018). The cognitive underpinnings of numerical representation in nonhuman animals have long been under debate. The accumulator

model assumes that animals cannot count numbers, but instead, represent numerical values as a compressed, single analog magnitude, which is proportional to the quantity it represents (Feigenson et al. 2004; Gallistel and Gelman 2000; Meck and Church 1983). This model predicts that errors committed by animals increase with increasing quantities. On the other hand, the object-file model states that animals encode separate items as distinct “object files”, an exact and absolute representation, limited in number to three or four, and that these representations can be used for discrimination between quantities less than or equal to the number of files (Beran 2007; Feigenson et al. 2004). Some researchers suggest that a combination of these two systems exists (Agrillo et al. 2012; Feigenson et al. 2004; Irie-Sugimoto et al. 2009). Such representations are reflected in their performance on a task involving relative quantity judgment (RQJ), which is a dichotomous judgment of numerical inequality ordered by magnitude (e.g., Davis and Perusse 1988; Dehaene 1997; Tomasello and Call 1997), and affected by distance and magnitude (or the sum of the presented comparisons) or ratio (calculated by dividing the smaller quantity by the larger quantity) of the comparisons. As the distance between presented comparisons decreases, or

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magnitude or ratios increase, the accuracy of discrimination decreases.

Previous studies have reported the unique RQJ performance by Asian elephants, where distance as small as one or magnitude up to eight do not affect RQJ task performance (Irie-Sugimoto et al. 2009; Irie and Hasegawa 2012), whereas African elephants are affected by these two factors (Irie 2012; Perdue et al. 2012). One possibility for this difference may be due to methodological problems (Perdue et al. 2012). Perdue et al. (2012) pointed out that when visual access to presented food amounts was controlled, the performance of African elephants could be explained by the accumulator model, consistent with the other species except Asian elephants and humans. This result was consistent with the study by Irie (2012) with African elephants, but not with the study by Irie-Sugimoto et al. (2009) or Irie and Hasegawa (2012) with Asian elephants. Another explanation for the inconsistency between studies may be cognitive differences between African and Asian elephants (Irie 2012). The Asian elephants and the two species of African elephants diverged more than 7.6 million years ago (Rohland et al. 2007), so it is highly probable that they developed different cognitive abilities. Irie-Sugimoto et al. (2009) suggested that Asian elephants might have “enlarged object file” representation, which suggests they have an increased number of object files compared to other animals.

In the present study, we introduced a new method to test the RQJ by elephants. To do so, we used a computer-controlled apparatus to rule out unintended factors, other than number of objects, which may have cued subjects in previous studies, and tested whether or not RQJ by Asian elephants is unique. In addition, we recorded response time to investigate whether their uniqueness can be explained by the enlarged object file model. If their numerical representation were enlarged object files, response time would not be affected by the magnitude (up to eight) or distance of presented comparisons.

The current study aimed to replicate previous results that Asian elephants may possess a unique numerical competence using a new apparatus. To do so, we used PC-controlled touch-panel stimuli specifically designed for examining elephant cognition (see Fig. 1). Our touch-panel experiment allows us to quantify not only the success rate, as in the previous studies, but also reaction time, which has been less frequently analyzed in previous studies of numerical competence in animals.

Methods

Subjects and housing

Three captive Asian elephants from the Ueno Zoo in Japan participated in the study, namely Artit (a 15-year-old male),

Fig. 1 Authai is performing the RQJ task on a touch-panel apparatus

Surya (an 18-year-old female), and Authai (a 14-year-old female). Elephants were housed and managed in facilities approved by the Japanese Association of Zoos and Aquariums. Housing also followed the Guidelines for the Management of Asian Elephants in Japan. The elephants were managed in a free-contact manner, ensuring that a zookeeper had free access to the enclosure, managed them, kept them clean, and trained them to obey certain vocal commands (e.g., “go”, “wait”, “sit down”). The elephants were fed four times a day (8:00, 11:00, 13:00, and 16:00 h) and had a diet of hay, soilage, and fruits. They were taken outside before the first meal (8:00 h) and returned to their cage before the last meal (16:00 h). They had free access to water at all times. A series of experiments were carried out in an outside playground (as described in detail below) before the third meal (13:00 h), except on rainy days, when the elephants would remain inside their cage all day. The elephant performing the task was out of view of the other elephants and the order of testing was randomly selected each day. Their weights were not specifically maintained for the purpose of the present experiment, and no animals were harmed in any way during the experiment.

Touch-panel apparatus

A 46" liquid-crystal display with a touch-panel (employing XYFer technology developed by EIT Co. Ltd.) fixed on the display was connected to a laptop and stabilized on a dolly. The task was presented on the display, with response time (in seconds) and subject selection for each trial automatically recorded in Excel files on the laptop.

Training sessions

Training sessions were conducted prior to the test trials and consisted of three steps. In step 1, the elephants were rewarded by a zookeeper for touching the screen with the tip of their trunk. In step 2, a figure (the “start button”, a red circle that was 40 cm in width, with the word “Start” in the center) appeared on the screen, and the elephants were rewarded by the experimenter when they touched the figure within 30 s.

In step 3, the elephant was kept standing in one place by its keeper at a distance of approximately 3 m from the touch-panel apparatus. Throughout the task, the keeper stood next to the elephant facing away from the touch-panel apparatus, so he could not give the elephant unintended cues. The start button used in step 2 appeared at the center of the screen; then, the experimenter pushed the apparatus towards the elephant such that it was at a distance of 2 m from the elephant. The experimenter stood behind the screen where she had no visual access to the surface of the screen to see the presented task and could not give the elephant unintended cues. The test trials began when the elephant touched the start button. Two figures containing discrete numbers of items [54 trials of “3 items vs 0 item” (3 vs 0); 78 trials of “4 items vs 1 item” (4 vs 1)] appeared simultaneously on the screen; when the elephant touched the figure with a larger number of items, we signaled the elephant with a neutral sound and image. The elephant was rewarded with a small piece of fruit when the experimenter heard the sound. If the elephant failed, a short beep (3 s long) was emitted, accompanied by 5 s of a blank screen. The sides of the screen in which the larger quantity appeared were counterbalanced within each session.

Items in the figures were pictures of fruit (Fig. 2; bananas, watermelons, and apples) in varying sizes to control for unintended cues such as the total area covered by the items. The percentages of the total areas covered by the items were randomized so that the percentages did not always represent the magnitudes of the numbers of items in each figure. The logistic regression analyses (1: correct, 0: incorrect) showed that Authai’s performance was not predicted by the magnitude ($\beta = -0.01$, $z = -1.23$, $p = 0.22$), the difference ($\beta = -0.004$, $z = -0.33$, $p = 0.74$), or the ratio ($\beta = -0.60$, $z = -0.98$, $p = 0.33$) of total area covered by the items between the two figures.

The session ended after six trials and the apparatus was taken away. The session was repeated four times a day.

Artit’s accuracy of step 3 was below chance level (49.73%) and Surya refused to come to the experimental setting after 2 sessions of step 3, therefore they did not move on to the test sessions. Authai’s accuracy in step 3 was above the “chance level” for both comparisons (72.2% for 3 vs 0; 64.1% for 4 vs 1, both $p < 0.05$, binominal test).

Fig. 2 Examples of figures presented in the task

Test sessions

As stated above, Authai was the only elephant who proceeded to the test trials. The experimental procedure was identical to the training session of step 3, except that two figures containing different numbers of items (0–10) were presented on the screen, and Authai was rewarded as in the training sessions, when she chose the figures with the larger number of items. The comparisons presented in the test trials were as follows: 2 vs 3, 3 vs 4, 4 vs 5, 5 vs 6, 6 vs 7, 7 vs 8; 1 vs 3, 2 vs 4, 3 vs 5, 4 vs 6, 5 vs 7; 0 vs 3, 1 vs 4, 2 vs 5, 3 vs 6; 0 vs 4, 1 vs 5, 4 vs 8, 2 vs 7, 5 vs 10, and 0 vs 6. Each comparison was presented in a random order (3–43 trials). Each session included the comparison 1 vs 4 at least once at the beginning to raise Authai’s motivation level, but the figures used were different from those in the training sessions. Twenty-four trial tests (6 trials $\times$ 4 sessions) were conducted per day.

Results

Authai chose the correct stimuli more often than chance choices, with 181 correct responses out of 271 times. The overall proportion of correct responses was 66.8% ($p < 0.01$, binominal test. See Fig. 3). We further analyzed the data according to the ratio, distance, and magnitude of the numbers of items. In contrast to the accumulator model, the proportion of correct trials was not affected by the magnitude, distance, or ratio of the comparisons [$\beta = 4.05$, -0.86 , and 0.51 ; $t(19) = 0.85$, -0.42 , and 1.38 ; $p = 0.40$, 0.68 , and 0.18 , respectively: univariate regression analysis]. Although the proportions of correct trials were low in the test trials of 0 vs 3 ($1/5 = 0.2$) and 0 vs 6 ($1/3 = 0.333$) (see Fig. 3), these

Fig. 3 The proportion of correct responses for each comparison (**a**, **b**, **c**) and the response time for each comparison (**d**, **e**, **f**). The response time diminished as the distance of presented quantities decreased (**e**)

results can possibly be explained by the fewer number of trials compared to the other trials (see electronic supplementary information).

Interestingly, reaction times were not affected by magnitude [$\beta = -0.04$, $t(268) = -0.74$, $p = 0.46$, univariate regression analysis], but were affected by the distance and ratio. Specifically, she required a significantly longer time to make her selection with relatively smaller distances and larger ratios [$\beta = -0.36$ and 0.01 , $t(268) = -2.41$ and 2.36 , $p < 0.05$, univariate regression analysis, see Fig. 3].

Discussion

This study showed a unique pattern for the RQJ performance in the Asian elephant, which has not been reported in other non-human animals. So far, Asian elephants are the only animal species, other than humans, that show no effects of ratio, distance, or magnitude on the accuracy of the RQJ (Irie-Sugimoto et al. 2009; Irie and Hasegawa 2012). Previous studies used the number of baits to present the comparisons, and therefore the presented quantities were directly associated with the number of rewards. This may have affected performance in various ways, such as making it difficult to maintain the subject's level of motivation. This study presented comparisons on a computer-controlled monitor and

the subject was rewarded with the same amount of food for each trial. Moreover, the analysis clearly ruled out the possibility of their use of an unintended cue, in this case, the total amount of area covered by the items. Under such conditions, we confirmed that the performance of the Asian elephant was not affected by the distance, magnitude, or ratio of the comparisons and that the numerical competence of Asian elephants was different from African elephants.

Moreover, Authai required a longer time to make a decision in comparisons with relatively smaller distances. This suggests that her numerical representation is not an instant, absolute representation as suggested in the object-file model; therefore, the enlarged object file model does not explain the unique performance of Asian elephants. Discrimination of quantities with smaller distances requires more precise and accurate representation of the subjects. Thus, her performance indicates that she required more time to increase the accuracy of the numerical representation, but not to represent increased magnitude. Because Authai's performance cannot be explained by the current hypotheses, it is highly likely that unique abilities enable Asian elephants to grasp the number of items with accuracy which is unaffected by ratio, distance, or magnitude. Note that their response time is affected by ratio and distance, but not by magnitude, while our counting takes longer with increasing magnitude. Therefore, it may not be a simple labeling of items (like

human counting) but rather her ability may have evolved in the Asian elephants independently. We speculate that Asian elephants share the combination of two numerical systems (accumulative and object-file), or accumulative representation alone, as in other species generally, but they also may have developed a new system that supports the primitive system to increase the accuracy of representation of given quantities. We would like to propose future studies to investigate the effect of magnitude, distance and ratio on the reaction time in the PC-controlled task by directly comparing the results with other non-human species. The future studies are necessary to test the hypothesis and determine what their “new system” is like.

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Compliance with ethical standards

Ethical approval Our study was approved by the Director of Ueno Zoo, after it was evaluated by the research and education committee at the zoo. Ueno Zoo is a member of the Japanese Association of Zoos and Aquariums (<http://www.jaza.jp/index.html>), which also has an animal welfare committee to confirm that Ueno Zoo meets their animal welfare standards as well. Since it was approved by the zoo, the current study meets the animal welfare standards of Japan.

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

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