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Kea (*Nestor notabilis*) consider spatial relationships between objects in the support problem

Alice M. I. Auersperg[1,2,*], Gyula K. Gajdon[1] and Ludwig Huber[1]

[1]*Department of Neurobiology and Cognition Research, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria*
[2]*Konrad Lorenz Institute for Ethology, Savoyenstrasse 1a, 1160 Vienna, Austria*
**Author for correspondence* (*alice_bayern@hotmail.com*).

The 'Support Problem' is a benchmark test to investigate the understanding of spatial relationships between objects. We tested kea parrots' performance in a paradigm that has previously been studied in primates. Kea perform comparably well to tamarins when they are confronted with a choice between two support devices, one of which has a reward resting on it and the other slightly next to it, or when given a choice between a continuous and a disrupted support. Kea did better than chimpanzees in some tasks in which the perceptual connection of the food to the support was altered. The results indicate that kea are capable of assessing the spatial means–end relationships of this problem spontaneously and in a way that is comparable with primates.

Keywords: physical cognition; means–end task; support problem; aves

1. INTRODUCTION

Knowledge about complex object relations can increase foraging efficiency and may be an important factor contributing to the evolution of intelligence (Byrne 1997). So far, cognitive abilities in the physical domain have been investigated most extensively in primates. Recent studies, however, suggest that some avian species have evolved higher cognitive abilities convergent to primates (Emery & Clayton 2004). Particular corvids and psittacines have achieved great success in physical tasks such as understanding cause–effect relationships, tool use and manufacture (Hunt 1996; Pepperberg 2004).

The 'Physical Support Problem', first formulated by Piaget (1952), is a classical means–end problem in which the subject has to pull a support as a 'means' to reach a desired 'end'. In a study by Funk (2002), young kakarikis succeeded in pulling a piece of cloth in order to reach the seeds resting upon it. Hauser *et al.* (1999) also used this design to test learning generalization in cotton-top tamarins. During their first task, the 'On Problem', subjects had to choose between pulling a cloth with a food pellet on it versus pulling another cloth with the same reward closely next to it. In the 'Connected Problem', subjects had to choose between a pellet resting on an intact piece of cloth versus another reward resting on a cloth that was cut in two pieces, and hence separated by a small gap. Herrmann *et al.* (2008) later tested the three great ape species on these tasks, and they showed outstanding mastery over the two problems. When Schmidt & Cook (2006) presented pigeons with the Connected Problem, however, the subjects required more than 100 trials to succeed. The experiment by Hauser *et al.* (1999) was replicated by de Mendonça-Furtado & Ottoni (2008) using a single blue-fronted amazon. The individual was tested in the On Problem only and took much longer to learn the task than the tamarins did.

To test whether subjects choose on the basis of a coherent form perception of the support around the food reward instead of the physical connection, Povinelli (2000) confronted chimpanzees with tasks where the food in the incorrect options was more perceptually contained within the optical field of the support, whereas it was less contained in the correct options. Chimpanzees performed at chance in these tasks, suggesting that they used the perceptual features rather than a concept of physical connection when making a choice.

The kea, a New Zealand parrot, proved to be competent in a vertical-pulling task, which involved some understanding of the physical 'connectedness' of objects (Werdenich & Huber 2006). The kea might likewise be an adequate model for addressing a horizontal-pulling task. The following study attempts to assess the performance of the kea, as an avian example, in several of the previous variations of the Physical Support Problem.

2. MATERIAL AND METHODS

Six juveniles between 13 and 15 months of age, two of which were males, and two subadult males at 4 years of age, participated in this study. They were all kept in one big outdoor aviary at the Konrad Lorenz Institute for Ethology, Vienna (see electronic supplementary material for a more detailed description of the methodology).

The apparatus consisted of a wooden box (60 cm × 30 cm × 30 cm) with a Perspex front that left a 4 cm gap at the bottom. Two red wooden slats (25 cm × 5.5 cm × 0.4 cm) were arranged in parallel (20 cm apart) underneath the Plexiglas partition (figure 1). A reward (peanut) could be obtained only by pulling the baited slat at its end (figure 1).

All subjects received basic training followed by five transfer tests (Hauser *et al.* 1999; Povinelli 2000). During the training sessions, one (two trials), both or neither (one trial each) slat was baited in random order.

Immediately before each of the following testing sessions, subjects had to successfully complete a given number of trials from the previous set-up as a precondition to continue (table 1). This ensured that the subjects were well motivated and attentive. If they failed the precondition, the procedure started again on the next day.

In the following 'On Problem' (three test trials per session), two equal rewards were used: one was placed on the end of one slat and the other was placed 1 cm from the end of the other slat. In the 'Connected Problem', both slats were baited, but one was interrupted by a 2 cm gap (six trials per session).

In the final problems for 'Control of Perceptual Containment' (six trials per session), four wooden slats, the ends of which were cut into four distinct shapes, were used (figure 1). In the first task 'Combination A', the reward appeared less contained by the

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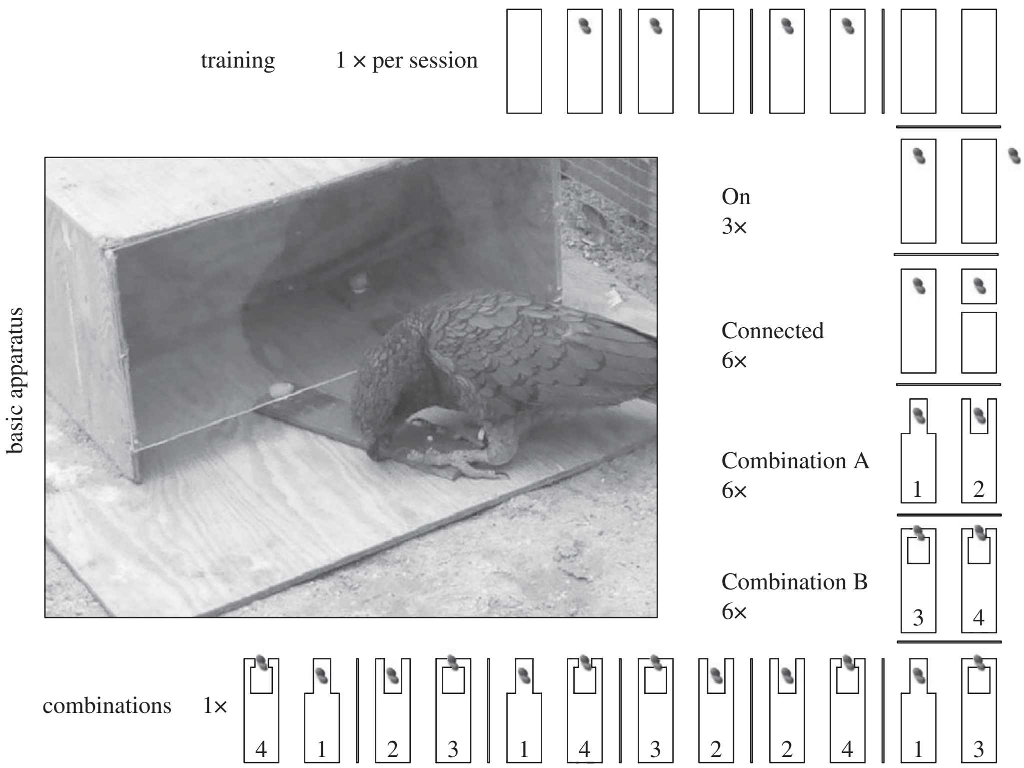

Figure 1. Paired slat combinations as offered in the various tasks. In the On and the Connected tasks as well as in Combinations A and B, the correct slat is semi-randomly allocated (for example 3× right; 3× left).

perceptual field of the correct slat (option 1) than of the incorrect option (2). In the next task ‘Combination B’, the incorrect option (4) seemed perceptually very similar to the correct option (3). In the final task, the birds were offered a combination of the previous options.

All subjects were tested in visual isolation from other group members. A trial was completed if a subject touched one of the slats; each subject was given one testing session per day and a maximum of 10 sessions for each problem. The number of trials per session and the criteria required for a subject to advance to the next task are depicted in table 1.

3. RESULTS

During training, the birds pulled the correct slat 92.5 per cent of the time in the first 10 trials. In the ‘neither slat baited’ condition, they stopped pulling altogether in the fifth session. Subjects did not show a side preference in trials in which both slats were baited (45% left; 55% right choices after five sessions).

In the On Problem, six out of eight birds chose correctly in their first trial and five reached significance within the first 10 trials. The youngest females, Lilly and Willy, however, both regressed to begging behaviour when faced with the apparatus in the course of this task and had to be excluded from further testing. In the Connected Problem, no kea except the juvenile male, Anu, performed above chance-level within 10 trials (table 1). Gino did not meet the requirement for passing onto the next stage after 10 sessions.

Four kea mastered Combination A and three subjects Combination B within 10 trials (table 1). After this condition, Plume and Anu had to be excluded from testing because of severe motivational difficulties. The three remaining subjects solved the last condition (Combinations C and D) within 10 trials (table 1). None of the birds could restrain themselves from pulling slats on the ‘none-baited’ condition of this task (Combination E).

4. DISCUSSION

Although our test subjects included six juveniles (kea reach maturity at 4 years of age), all birds expeditiously accomplished the On Problem. This is remarkable, given that in a similar situation in which two infant (19-month-old) chimpanzees had to choose between two pieces of cloth, one of which carried a reward, only one subject was capable of solving the problem (Spinozzi & Potí 1993). Similar to the kea, adult tamarins made 78 per cent correct choices on the first trials of the On Problem (Hauser *et al.* 1999). The amazon tested by de Mendonça-Furtado & Ottoni (2008) in contrary, took over 600 trials to reach its criterion in the On Problem. This neo-tropical parrot had presumably learned to memorize the fused food–reward perceptual form as the correct option.

The kea displayed initial difficulties with the Connected Problem. They chose correctly in 42 per cent of the first two trials, but reached 75 per cent in trials 3 and 4. This renders it unlikely that the subjects perceived the disrupted condition as two separate pieces as opposed to a single piece disrupted by a gap as put forward by Povinelli (2000).

Three kea mastered all perceptual containment tasks surprisingly fast and accurately and did not decrease in performance after the combinations were intermixed. In contrast, the chimpanzees tested by Povinelli (2000) were not capable of solving any similar combinations spontaneously above chance level. It should be recalled at this point that the visual acuity of birds is about two to three times better than that

Table 1. Summary of the results for the different conditions for each subject.

condition	subject	criterion	precondition	trials/ session	1st trial correct	% correct 1st 10 trials	*p*-values, binominal test $n = 10$
training	Zappel[a]	8 consecutive		4	yes	100[b]	0.001
	Linus[a]	correct			yes	90[b]	0.001
	Gino	choices			yes	100[b]	0.001
	Anu				yes	100[b]	0.001
	Hope				yes	90[b]	0.001
	Plume				yes	80[b]	0.044
	Willy				yes	80[b]	0.044
	Lilly				yes	90[b]	0.001
on	Zappel[a]	2 sessions	1 training	3	yes	100[b]	0.001
	Linus[a]	correct	session		yes	100[b]	0.001
	Gino				no	70	0.117
	Anu				yes	90[b]	0.001
	Hope				yes	90[b]	0.001
	Plume				yes	80[b]	0.044
	Willy				no	70	0.117
	Lilly				yes	60	0.205
connected	Zappel[a]	5 consecutive	3 on trials	6	no	60	0.205
	Linus[a]	correct			no	50	0.246
	Gino	choices/			yes	70	0.117
	Anu	session			yes	100[b]	0.001
	Hope				no	60	0.205
	Plume				yes	60	0.205
A	Zappel[a]	5 consecutive	3 connected	6	yes	90[b]	0.001
	Linus[a]	correct	trials		yes	100[b]	0.001
	Anu	choices/			yes	80[b]	0.044
	Hope	session			no	70	0.117
	Plume				yes	100[b]	0.001
B	Zappel[a]	5 consecutive	3 A-trials	6	no	80[b]	0.044
	Linus[a]	correct			yes	90[b]	0.001
	Anu	choices/			no	70[b]	0.117
	Hope	session			yes	100[b]	0.001
	Plume				yes	80[b]	0.044
C and D	Zappel[a]	5 consecutive	2 A-trials,	6	yes	100[b]	0.001
	Linus[a]	correct	2 B-trials		no	80[b]	0.044
	Hope	choices/			yes	100[b]	0.001
		session					

[a]Subadult males.
[b]Values significantly above chance.

of primates (Lythgoe 1979), which might have facilitated their choices.

Nevertheless, it is difficult to determine to what degree the kea were capable of recognizing a sophisticated concept behind the problem. The Connected Problem should generally rule out that the animals had learned simply to choose any option in which the reward was placed on the support material ignoring the connection between the same material and their reach. All kea tested on the Connected Problem apart from Anu did not master this challenge immediately, but succeeded eventually after a few sessions. It is therefore possible that most of them initially applied the previous rule before accommodating to the new task. The results of the perceptual containment combinations, however, render it unlikely that they made their choices based on the fusion of form between reward and support.

Kea at this age class have an extraordinarily intense and complex play behaviour (Diamond & Bond 2004). In contrast to the blue-fronted parrot (de Mendonça-Furtado & Ottoni 2008), kea typically spend a lot of time during the day playing with objects on the ground as many primates do (Diamond & Bond 2004). The juveniles and subadults in our aviary are frequently seen carrying objects, putting them on top of each other and even carrying an object with another one placed on top of it. Through experience they might have developed an intuitive assessment of the effect the movement of an underlying object may have on another one resting on top of it and vice versa. An acquired knowledge/intuitive understanding can be applied when confronted with the Support Problem without requiring a more abstract folk physics, i.e. that it is the weight of the top object that establishes the physical connection to the support (Povinelli 2000).

Our findings demonstrate that the ability to spontaneously consider means–end relationships in the support problem is not monopolized by primates. To investigate to what degree this decision-making process underlies a causal inference is still a quest for future research.

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