

## Do bee eaters have theory of mind?

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**Theory of mind, or the ability to think about another individual's mental states, is not widely known in animals. We describe in this paper a test for the theory of mind in birds and present suggestive evidence for theory of mind in the small green bee eater. Bee eaters were observed to hesitate entering their nest in the presence of a human observer. The hesitation was significantly reduced when the observer was unable to see the nest, although the bird could see the observer clearly and at a comparable distance. This suggests that the birds can appreciate the visual perspective of the observer and take a decision based on the observer's vision. Further, if the observer had seen the nest before in the presence of the bird, the frequency of nest visits was observed to be less than that when the observer had not seen the nest, suggesting that the bird can probably differentiate what the observer knows and what he does not. Such a behaviour needs a mental capacity so far only known in humans and a few other primates.**

THE ability to appreciate the mental states of other individuals is called the 'theory of mind'<sup>1-8</sup>. This involves realizing another individual's intentions or at least realizing that another individual's perception and thinking can be different from one's own. A human child develops this ability by the age of three and a half years<sup>2,3</sup>. Children with autism, a kind of developmental retardation, do not fully develop the theory of mind<sup>4,5</sup>. The underlying deficit in autism is suggested to be an inability to hold in memory two sets of mutually contradicting information<sup>6</sup>. This deficiency probably results in the inability to appreciate that another person's perception of a situation can be different and at times contradictory to one's own. It is well recognized today that theory of mind is a plurality. Levels are recognized in this mental ability and in humans first order and higher order tasks are devised corresponding to the levels<sup>8,9</sup>. Attribution of certain mental states is believed to be easier than others. For example 'see' and 'want' is said to be easier than 'believe' or 'know'<sup>9</sup>.

Most animals are believed to lack a theory of mind. Evidence for its existence is reported from apes<sup>1</sup>, whereas monkeys do not seem to recognize mental states of others<sup>10</sup>. Theory of mind in animals can be demonstrated only if it brings about a detectable and preferably quantifiable behavioural change. The experimental de-

signs and interpretations for testing aspects of theory of mind in primates are under debate and many researchers believe that there is still no convincing evidence of theory of mind in non-human primates and all the positive evidence presented so far has found some non-mentalistic explanations<sup>7</sup>.

We designed a field experiment on breeding birds which can be used as a simple test for theory of mind in birds. Small birds tend to build well-camouflaged nests. The inconspicuousness of a nest is its best protection. For the camouflage to be effective it is also necessary that the bird's behaviour does not betray the nest site. Some birds therefore avoid entering the nest in the presence of a potential nest predator. It is also possible, for some species of birds including the bee eaters, that the bird is more vulnerable when inside the nest. Therefore the hesitation to enter the nest in the presence of a potential predator might be for the bird's own safety. A number of species show such a hesitation in response to a human observer, while some species do not<sup>11</sup>. Using this behaviour exhibited by the small green bee eater (*Merops orientalis*), we show here that the bird can appreciate the perspective of the observer and behaves as if it can understand what the observer 'knows'.

The small green bee eater is a tropical bird distributed widely in India and having a number of related species (family Meropidae) in the old world tropics. These insectivorous birds nest in mud cliffs, river banks and gently sloping bare grounds. The sexes are alike and both the parents feed the chicks. The nest is in the form of a tunnel. The peak breeding season is in the months of May and June<sup>12</sup>. We located 8 bee eater nests in two consecutive breeding seasons (May 1997 and 1998) for the observations. At each of the nests the parent birds were observed to use one or a few perching sites from where they would normally take a direct flight to the nest. The observer positioned herself in two alternative positions. From position I, both the nest and the perch were visible. From position II, the perch was visible but the nest was not. The second position was selected such that the distance from the nest was comparable to position I, but a screen in the form of a bush, a wall or a rock face prevented direct view of the nest. The direction of gaze of the observer from both the positions was towards the perch. The observer's distance from the nest ranged between 3 and 23 m and from the perch 1 and 25 m. The bird from its perch was able to see the nest, the observer as well as the screen. Taking positions I and II randomly, the observer recorded the time taken by the bird to enter the nest. From either positions a unit observation period typically of 30 min was used and the number of visits to the nest was recorded. All observations were confined to 6.00-11.00 and 17.00-19.00 h which were the hours of active feeding. No nest was observed for more than two hours at a stretch and for more than two consecutive days to keep the effect of

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**Table 1.** Frequency of visits to the nest by the parent birds when the observer can (position I) and cannot (position II) see the nest

Nest code	Position I (nest visible)			Position II (nest not visible)		
	Time observed (h)	No. of visits	Frequency	Time observed (h)	No. of visits	Frequency
A	3.30	9	2.72	3.20	35	10.93
B	2	5	2.5	2	11	5.5
C	2.35	27	11.48	2.15	13	6.04
D	1.45	3	2.06	1.45	17	11.72
E	1.25	7	5.6	3.15	38	12.06
F	3	8	2.66	3	17	5.66
G	3	11	3.66	3	20	6.66
H	3	7	2.33	3.15	14	4.44

Cumulative data on eight nests.

habituation to a minimum possible. The bird could clearly see the observer at positions I and II, therefore no difference is expected in the frequency of visits to the nest if hesitation in visiting the nest was simply a response to the presence of the human observer. On the other hand, if the bird realized that the observer could not see the nest from position II, it can be expected to be less hesitant.

The mean frequency of visits when the observer was at position II was greater than position I for 7 out of 8 nests (Table 1). The frequency of visits is likely to depend upon the number and age of chicks in the nest in addition to a number of other local and temporal factors and therefore a large variance in frequency across nests is expected. We therefore avoided parametric tests on cumulative data for statistical analysis and only compared the frequency of visits to the nest in pairs of observations from position I and II in immediate succession, the sequence of taking position I and II being random. Paired comparisons of nest visiting frequencies showed that out of 37 paired observations, in 24 pairs the frequency of visits in position II was greater than position I and in only 4 pairs it was smaller. The difference was highly significant ( $P < 0.01$ ) using Dixon and Mood's sign test<sup>13</sup>. Out of the 4 negative results, two come from nest C, for which the cumulative results were also negative.

The frequency of nest visits significantly increased with increase in the distance of the observer from the nest as well as from the perch as shown by the Pearson's product moment correlation coefficients (distance from the nest,  $r = 0.283$ , distance from the perch  $r = 0.3266$ ,  $n = 79$ ,  $P < 0.01$ ). The positive correlations show that the birds responded to the observer as they would respond to a potential predator although the response to humans could be milder than that to true predators. After plotting a regression line through the scatter of distance from the perch and frequency, it was seen that the majority of points for position II (19 out of 37) lie

above the line and for position I (29 out of 37) below. The difference was significant using a  $\chi^2$  test ( $\chi^2 = 7.056$ , d.f. = 1,  $P < 0.01$ ). The difference thus remained significant after controlling for the effect of observation distance.

The frequency of nest visits was not the only behaviour affected by the observer's position. The birds showed a number of responses such as taking off in the direction of the nest but returning immediately, circling over the observer or shifting its position on the perch. Such behaviours may reflect indecisiveness. The frequency of these behaviours was more when the observer was at position I, although we did not quantitatively analyse these for the difficulties in defining and classifying such behaviours.

Significant differences in the nest visit frequencies between position I and II indicate that the bird was able to judge whether the observer could see the nest from its position, since barring the screen obscuring the view of the nest for the observer, there was no other obvious factor that could affect the bird's decision. A number of mechanisms by which the bird could make this judgment can be speculated. The bird has to either:

- (i) possess a sense of geometry to realize that the observer, the screen and the nest lie in a straight line and therefore the screen should mask the nest view;
- (ii) Retrieve from its memory the perspective from the observer's position;
- (iii) try to find out what the perspective from the observer's position was by flying some distance towards the nest and looking at the observer or vice versa.

It is also possible that the bird, once into the nest after the first visit, did not see the observer in position II and therefore was less hesitant on subsequent visits. Such a process can be based on learning and does not need theory of mind. This is testable by looking at the differ-

ence in the time taken to visit the nest for the first time after the observer takes a new position. We found that the birds took significantly longer for their first visit (Table 2) when the observer could see the nest, indicating that simple learning is not a sufficient explanation for the difference. There is evidence for the third of the above hypotheses since some of the birds were noticed to take flights half way to the nest and thus possibly employ some trial and error procedure. This however, was not seen in all the cases. For the nests where this behaviour was not recorded at all, there still was substantial difference in frequencies at the two positions. This mechanism therefore is possible but not sufficient to explain the difference in all cases. For two of the nests this behaviour was most frequent. The observer distance for these two nests was also maximum. For short observer distances, on the other hand, indecisive responses were infrequent or absent. It is speculated that the birds could appreciate the geometry well when the triangles were small and were more indecisive when the distances were more than 15 m. In any case, a trial and error learning is not likely to be a sufficient explanation for the difference in frequency.

This makes the first or the second mechanism more likely. For both of the mechanisms the birds have to make the decision from the perch itself and since the decision is necessarily based on the observer's view of the nest, the birds must be capable of thinking about what the observer could see.

It has been argued that having a concept of 'see' does not necessarily imply attribution of knowledge<sup>14</sup>. Therefore demonstrating that the birds have the concept of see is not sufficient to claim theory of mind. A careful look at the same experiment, however, can take us beyond 'see' and ask the question whether the birds can think of

what the human observers 'know'. If the observer standing at position I, has seen the bird entering the nest, the bird may infer (if it has the ability to do so) that the observer knows where the nest is. If such an observer now takes position II, the bird might continue to hesitate if it can attribute knowledge to the observer. If the bird does not have a concept of 'know', the response to this observer will not be different from the response to one taking position II first. The mean frequency of visits when position II was taken first was 14.75/h and that when position II followed position I was 5.08/h, being only marginally greater than position I. In paired comparisons, the difference was significant (Dixon and Mood's sign test  $R = 2$  in 12 informative pairs,  $P < 0.05$ ). The effect of habituation or learning that the observer is harmless, is expected to increase the frequency of nest visits with continued observations. In spite of this possible bias, the frequency of visits when position II was taken after position I was significantly less as compared to freshly taken position II. No such difference was observed in the frequency at position I. The frequency when position I was taken first was 2.31/h and that for position I following position II was 4.55/h. This difference is likely to be an effect of habituation, but was not significant in a paired comparison. This points to the possibility that the birds change their behaviour according to what they think the observer 'knows' and not only to where it is.

It would not be out of place to add an anecdote. In order to find nests of small birds, a number of bird watchers have been using a simple trick. Whenever a bird is observed carrying insects or some other food in the beak and not devouring, the bird watcher starts suspecting a nest in the vicinity. The bird, however, does not go to the nest as long as it is being watched. The bird watcher then pretends to gaze in some other direction or walk away. The bird usually takes a flight towards the nest in a short time. This protocol was successfully used to find some of the nests in the present study as well. Using the direction of gaze of another individual is one of the mental qualities that autistic children lack<sup>15</sup>. Although in this experiment we did not test for this ability quantitatively, it remains an interesting proposition to test.

The results have important implications for research in animal intelligence and cognitive behaviour. The experimental design lays out a quantifiable framework for testing theory of mind and geometrical perception in animals, where in a generalized case the nest can be replaced by a food source or any other focus of activity and the observer by any individual who can be a stimulant or deterrent of the activity. All the animal experiments for testing theory of mind and related mental abilities have attracted criticism. The critics have either pointed out flaws and inadequacies of the protocol or more commonly suggested alternative explanations that do not need mental states<sup>7</sup>. On the other hand, the num-

**Table 2.** Time taken by parent birds to visit the nest for the first time when the observer takes on a new position

Time for first visit (min) position I	Time for first visit (min) position II
8	8
5	1
>30	24
>30	4
23	>30
11	5
>30	1
21	3
10	10
5	5
>30	>30
24	8
>30	16
25	8
>30	20
15	10
18	25
14	14

ber of claims of cognitive and even conscious processes in animals are on the rise<sup>16</sup>. We do not intend to address this debate here, but suggest that only carefully designed novel experiments can provide a breakthrough.

With respect to experiments and evidence, there have been advocates of naturalistic observations on the one hand<sup>17</sup> and carefully controlled protocols with trained captive animals on the other<sup>7</sup>. The naturalistic approach suffers from problems such as being anecdotal or relying on convergence<sup>7</sup> whereas captive experiments are criticized on account of the problems associated with training and the artificiality and arbitrariness of tasks<sup>17</sup>. We do not claim our protocol to be immune to criticism or alternative explanations. It is however, a good combination of natural conditions and experimental manipulations. The task given to the birds is close to what they may be required to do naturally. At the same time the experimental situation is reproducible and there are adequate controls. The experiment also opens up the field for non-primate studies on theory of mind.

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## Sequences that facilitate high fidelity of pairing by RecA: A model

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**Homologues of *E. coli* RecA in eucaryotes (Rad 51) are conserved during evolution in their structural and physical properties. They form structurally similar presynaptic filaments on single-stranded DNA. These proteins bind to certain sequences that are G- and T-rich with higher affinity. Hot-spots of recombination in *E. coli* are embedded in GT-rich stretches. The DNA bases in the presynaptic filament show a high degree of promiscuous pairing excepting the C residue, which is paired with a high degree of fidelity. A model is proposed in this study, suggesting that the binding preference and pairing fidelity are two separate parameters that might together ensure proper recombinational pairing in hot-spots.**

RECOMBINATION hot-spots is well characterized in *E. coli* and *S. cerevisiae* at the genetic and molecular level<sup>1,2</sup>. In higher eucaryotes such as mammals and plants, a few candidate sequence motifs are described as recombination hot-spots<sup>3–5</sup>. In spite of a wealth of information on hot-spots in *E. coli* and *S. cerevisiae*, there is no obvious consensus at the DNA level as to what makes a region 'hot-spot' for recombination. In this paper, we try to focus on this issue and propose a molecular model for the same. This proposal is based on our work on *E. coli* RecA as well as that published from Stephen Kowalczykowski's lab<sup>6,7</sup>. A genetic hot-spot is characterized by extrinsic and intrinsic factors. The former includes accessibility to the recombination machinery and chromatin structure. Intrinsically, a 'hot-spot' should contain DNA sequences that might have higher affinity to RecA protein and thereby promote a relatively stable RecA nucleoprotein filament that initiates recombination at a higher frequency. It should also have DNA sequences that can pair well with homologous sequences. Recent work addresses the issue of RecA affinity<sup>6</sup> whereas our results provide an insight on the pairing preferences of RecA. In this communication, we have focused on the intrinsic factors that influence recombination.

An *in vitro* selection was performed in a random pool of 10<sup>14</sup> oligos which were 70-mers and a pool of 10<sup>11</sup> 18-mers to select sequences that have higher affinity for RecA binding<sup>6</sup>. Both selections were done with limiting concentrations of RecA. Several cycles (eight for the 70-mer pool and five for the 18-mer pool) of selection and PCR amplification yielded sequences that were substantially rich in G and T bases. The average base percentages of several such clones were: (from the 70-mer