The more the merrier: dogs can assess quantities in food-choice tasks

Arunita Banerjee and Anindita Bhadra*

Department of Biological Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur 741 246, India

Animals in their natural environment often face situations where it may be advantageous for them to be able to make decisions based on numerical or quantity discrimination. Canids like pet dogs, wolves and coyotes have been known to have a preliminary sense of number. We tested 303 unique free-ranging dogs for seven food-choice tasks, skewed in terms of stimulus: olfactory, visual and reward obtained. The dogs primarily used olfactory cues in the decision-making process, rather than visual cues, to discriminate between different quantities in a context-dependent manner.

Keywords: Food-choice task, free-ranging dogs, numerical cognition, quantity discrimination, stimulus.

NUMERICAL cognition refers to the presence of an innate number sense faculty which enables distinction between quantities of relative sizes[1]. This may confer additional fitness and survival advantages to individuals. The existence of an 'approximate number system' (ANS) has been found in human adults, human infants (pre-verbal) and non-human species alike[2,3]. Numerical cognition studies have been conducted on many non-human species like chimpanzees (*Pan troglodytes*)[4,5], capuchins[6], fishes[7], amphibians[8], black bears[9], elephants[10], insects[11], birds[12], etc.

Several studies have been conducted to test numerical cognition in canids. Studies on dogs[13,14], wolves[15] and coyotes[16] have reported successful results using two popular protocols for numerical cognition – two-way spontaneous choice test and violation of expectancy paradigm[15]. Human-raised wolves have been observed to perform well in choice-based tasks of having to choose between two sets of 1–4 food items, kept in opaque cans[17]. Studies have suggested that wolves perform much better than pet dogs or captive pack dogs, in contexts of physical cognition[18]. Pet dogs, however, perform better than captive pack dogs and wolves in contexts of social cognition[19]. When studied in the context of a choice-based task, quantity discrimination is an aspect of physical cognition. On the other hand, when studied in the context of a real-life situation involving inter-specific interactions, quantity discrimination plays a subtle role in understanding social cognition of the concerned animal. Canids as a family clearly seem to have a number sense faculty, based on their own mental representation of many and few. However, most of these studies have been carried out with captive individuals or pets, who are not exposed to the uncertainties of the natural habitat. An ability to count can be of great advantage to free-ranging animals, as it would help in guiding foraging decisions, conflict decisions and monitor offspring. In this study, we assessed the counting/quantity discrimination ability of free-ranging dogs using a two-way spontaneous choice-based task.

Number/amount/preference, when skewed between two parallel options (one being larger than the other, or one having a stronger smell than the other, or one being the more preferred food type than the other), provides a stimulus for the animal. The animal is presented with similar numerical cues in many real-life situations like territorial fights, keeping track of group members or offspring, assessing quantities of food, etc. The decision of discrimination may depend on the context in which it arises. It cannot be pre-determined if the animal will take a decision in favour of a larger numerical value (more versus less quantity of food available), or a smaller value (in case of a territorial fight, if the group size of the opposition is smaller than the self-group size), or simply be neutral to the situation but keep track of the numerical value (e.g. the number of pups of a mother). Since free-ranging dogs are known to be opportunistic feeders, we hypothesize that the animal will choose the larger of the two food options provided.

Numerical cognition is characterized by psychophysical signatures like ratio dependence and semantic congruity, in both human and non-human systems[2]. According to Weber's law, discrimination between two numerical entities are mediated by the ratio between them[20]. As the ratio tends to 1 : 1, the discrimination becomes more difficult for both humans and non-human model organisms. In about a decade-old study where dogs were tested in a similar food choice-based task and the ratios involved were 1 : 2, 1 : 3, 1 : 4, 2 : 3, 2 : 4, 2 : 5, 3 : 4 and 3 : 5, majority (15 out of 29) chose the larger of the two quantities and the performance of the dogs adhered to Weber's law[13]. Another study which tested 27 pet dogs in a food-choice task, for the ratios 1 : 0, 1 : 2, 1 : 3, 1 : 4, 2 : 4, 2 : 3, 3 : 4, found that 100% of the dogs chose the larger of the two quantities for 1 versus 0, but failed to perform above chance for the other ratios[21]. The ratio 1 : 4 was found to be the most difficult among those tested. In order to normalize the present study and gain insight into the decision-making process of dogs, we have maintained a numerical ratio of 1 : 4 throughout the study and have skewed the combinations of the two food choices on the basis of visual cues, olfactory cues and preference of food type. Since this is a choice-based task, the number sense of dogs was tested as an aspect of physical cognition.

We performed a set of seven choice tests with different options on a total of 303 adult, free-ranging dogs in and around the Indian Institute of Science Education and

*For correspondence. (e-mail: abhadra@iiserkol.ac.in)

Research (IISER), Kolkata campus at Mohanpur (21.8398°N, 87.4232°E), West Bengal, India. Only 269 dogs showed interest in the task; the rest were excluded from analysis. Each dog was tested individually, and all experiments were performed on the streets of semi-urban areas. If the dogs were found in groups, the other dogs were lured away with food, separating one dog at a time, which was subjected to the task. All food items used were suitable for human consumption, and no dogs were harmed during the experiment. Since free-ranging dogs are known to be opportunistic feeders, and the amount of food reward used in the experiment was small, we do not expect the hunger levels of these animals to bias the experiment in any manner.

We used a series of choice tests, each with two options to test the ability of free-ranging dogs to differentiate between different numerical parameters. The food choices were provided in transparent (cellophane) packages, so that both olfactory and visual cues were available to the dogs. The packages were prepared by placing chicken salami pieces/biscuits on a piece of cellophane, covering this with another piece of cellophane and using cello tape to seal the sides. Half a slice of chicken salami, weighing approximately 14 g and having a diameter of approximately 6 cm, was considered to be one whole piece of chicken. For the food preference skew, biscuits of approximately the same weight and size as of the half slice of salami were used. Previous studies have shown that free-ranging dogs have a preference for meat (protein) over biscuits (carbohydrate)[22]. One of us (Arunita Banerjee) placed the two packages simultaneously on the ground at approximately 0.3 m way from the dog and stepped back to assume a neutral posture, looking straight ahead, thereby avoiding making eye contact with the dog (ESM, Supplementary Video). The experiment was concluded 1 min after placing the packages on the ground or until the dog made a choice, whichever was earlier. The entire experiment was video recorded and analysis was carried out by coding the videos at the end of the experiment.

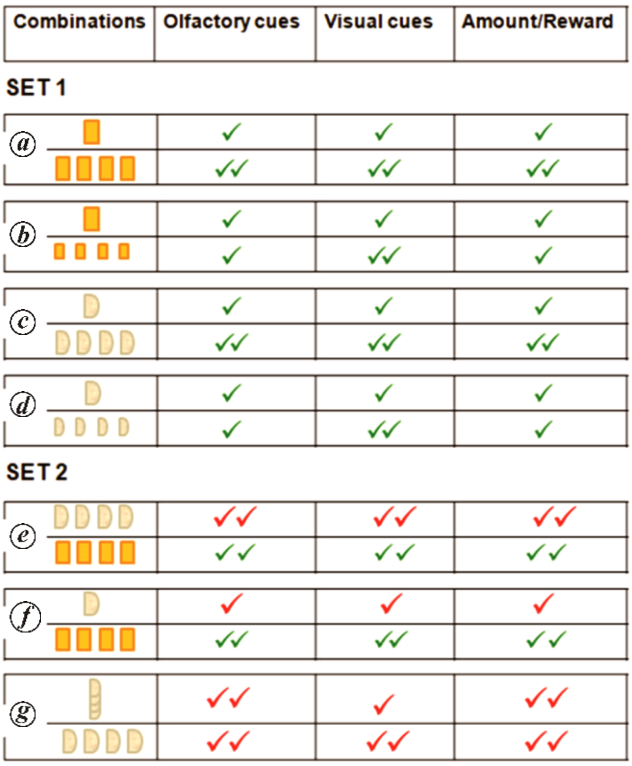

Figure 1. Schematic showing combinations of choices offered in two rounds of experimental trials and the skewed cues in each case. ***a***, One whole biscuit vs four whole biscuits (1B vs 4B). ***b***, One whole biscuit vs four pieces of that whole (1B vs 4QB). ***c***, One whole chicken vs four whole chickens (1C vs 4C). ***d***, One whole chicken vs four pieces of that whole (1C vs 4QC). ***e***, Four whole chickens vs four whole biscuits (4C vs 4B). ***f***, One whole chicken vs four whole biscuits (1C vs 4B). ***g***, Four whole chickens stacked vs four whole chickens spread out (4stC vs 4spC). Green tick marks depict non-preferred food option while red tick marks depict preferred food option which cues have been offered less (one tick) or more (two ticks).

A total of seven combinations were designed such that they were skewed in terms of olfactory cues, visual cues, reward and preference (Figure 1). The experiments were performed in two sets; the first set was designed primarily to test the ability of the dogs to distinguish between one and many of the same food type. The second set was designed to understand which cues were used by the dogs to make their choice. A total of 303 adult free-ranging dogs were subjected to the task, of which only 269 showed interest and responded to the task. The others were excluded from analysis. Sampling locations were chosen randomly. In order to ensure that the same dog was not tested twice, the experiment was performed in a different area on each day.

The following parameters were used to analyse the data:

(i) Latency – Time taken by the dogs to show interest after the packages are placed on the ground.

(ii) Approaching time – Time duration from the moment of first interest to first contact (using snout, tongue or paw) with one of the packages provided.

(iii) Selection time – Time duration from the moment of first contact to final selection or until the end of 1 min (whichever was earlier).

(iv) Choice – Final selection made by the dog (trying to open a package using teeth or paws was considered as selection).

Test of proportion was used to compare the final selection responses received in each set of trials. Chi-square test were performed to compare the selection (when the dog chose at least one packet) and no-selection (when the dog did not choose any packet) situations across the two food types – preferred (chicken) and non-preferred (biscuit). The measured parameters were compared using Mann–Whitney U tests. Chi-square tests were used to compare three specific situations which were skewed for both olfactory and visual cues, in order to determine the cue used in the decision-making process. Data analysis was carried out using StatistiXL 2.0 and R 3.3.3 (ref. 23).

Set-1 experimental trials were performed on a total of 166 dogs, of which 26 did not respond to the task at the end of the cut-off time of 1 min and were thus discarded from further analysis. For both biscuit and chicken options, i.e. both packages containing chicken options and both packages containing biscuit options, the dogs showed equal levels of interest (test of proportions: $\chi^2 = 2.9138$, DF = 1, $P = 0.08$). However, comparison of selection and non-selection situations within each category revealed that selection responses were higher when both options contained chicken, than when both options were biscuits (contingency chi-square: $\chi^2 = 9.856$, DF = 1, $P = 0.002$) (Figure 2).

When the final choice made by a dog in each of the categories was compared, it was found that a random selection was made in three out of the four cases (Table 1). Only in one case, four whole pieces of chicken were selected significantly more often than one whole piece of chicken (test of proportion: $\chi^2 = 24.242$, DF = 1, $P < 0.01$), but no such clear choice existed for the other three cases (tests of proportion: 4B versus 1B: χ^2 = 5.0894e-32, DF = 1, $P = 1.0$; 4QB versus 1B: $\chi^2 = 0.1$, DF = 1, $P = 0.75$; 4QC versus 1C: $\chi^2 = 0.56$, DF = 1, $P = 0.45$).

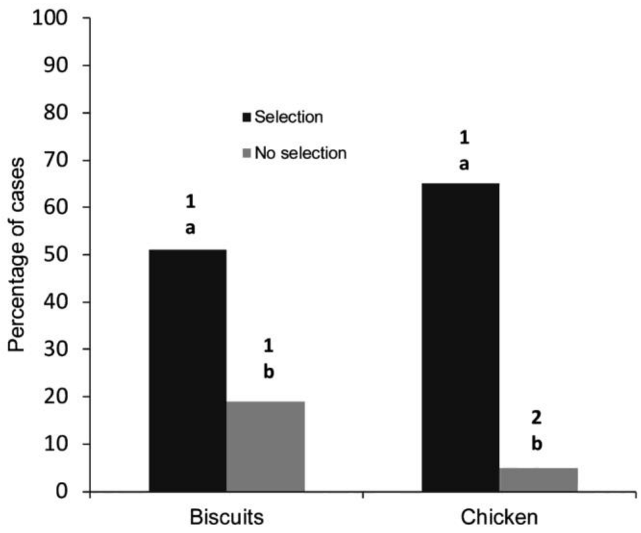

Figure 2. Bar graph showing comparison between selection and non-selection responses across the two food types (biscuit and chicken options). Different letters suggest significant difference within a food type, different numbers suggest significant differences between selection (or no selection) across food types.

Table 1. Final choice by dogs in the set-1 experimental trials

Types of option	No. of dogs tested successfully	No choice	Choice 1	Choice 4
1B vs 4B	35	4	15	16
1B vs 4QB	35	15	11	9
1C vs 4C	35	2	6	27
1C vs 4QC	35	3	14	18

The other parameters, i.e. latency, approaching time and selection time were compared for the biscuit category options (where both options contained biscuits) and the chicken category options (where both options contained chicken). The latency (Mann–Whitney U: $U = 2660.0$, $DF_{1,2}$ = 70, 70, $P = 0.384$; Figure 3 *a*) and approaching time (Mann–Whitney U: $U = 2796.5$, $DF_{1,2}$ = 70, 70, $P = 0.149$; Figure 3 *b*) did not show any significant difference. The selection time when compared across the same categories showed a significantly higher value for biscuits (Mann–Whitney U: $U = 3449.0$, $DF_{1,2}$ = 70, 70, $P < 0.001$; Figure 3 *c*).

Set-2 experimental trials included 137 dogs, of which 8 did not respond to the task within the cut-off time of 1 min and were thus discarded from further analysis. It was found that the dogs show a selection preference for four whole chicken units compared to four whole biscuit units (test of proportion: $\chi^2 = 5.94$, DF = 1, $P < 0.05$; Figure 4 *a*). However, no significant preference for selection was seen in the other two cases, viz. 1C versus 4B (test of proportion: $\chi^2 = 0.025$, DF = 1, $P = 0.87$; Figure 4 *b*) and 4stC versus 4spC (test of proportion: $\chi^2 = 1.94$, DF = 1, $P = 0.16$; Figure 4 *c*). This confirmed that the selection made by the dog was context-dependent. It also indicated that the dogs may decide upon the selection on the basis of quantity (less or more) and not numerosity (few or many).

Comparison of three specific cases skewed for olfactory and visual cues, viz. 1C versus 4QC, 4stC versus 4spC and 1C versus 4C showed significant difference across that the final choice obtained (contingency chi-square: $\chi^2 = 14.081$, DF = 2, $P < 0.05$). However, when the former two cases (1C versus 4QC and 4stC versus 4spC) were compared, no significant difference across the final choice was seen (contingency chi-square: $\chi^2 = 2.585$, DF = 1, $P = 0.108$). This confirmed that the decision-making process of the dogs was guided by olfactory cues and not visual cues (Figure 5).

Existing studies of numerical cognition have primarily used two types of methodologies; a two-way spontaneous choice test and violation of expectancy paradigm[15]. The former is a choice-based task, wherein two sizes/quantities/numerically different food options are placed in front of the animal, sequentially or simultaneously, and the animal is allowed to choose between them. The two options are made visible to the animal during the decision-making process or at some point before it makes the final decision. Studies in canids have shown successful results using both the aforementioned protocols[13–16,21].

One of the first influential papers[24] in the field of numerical cognition in non-human model organisms presented a few critical issues in this area, one of the greatest problems being whether numerical competence in animals should be termed as ‘counting’ or not[24]. In the

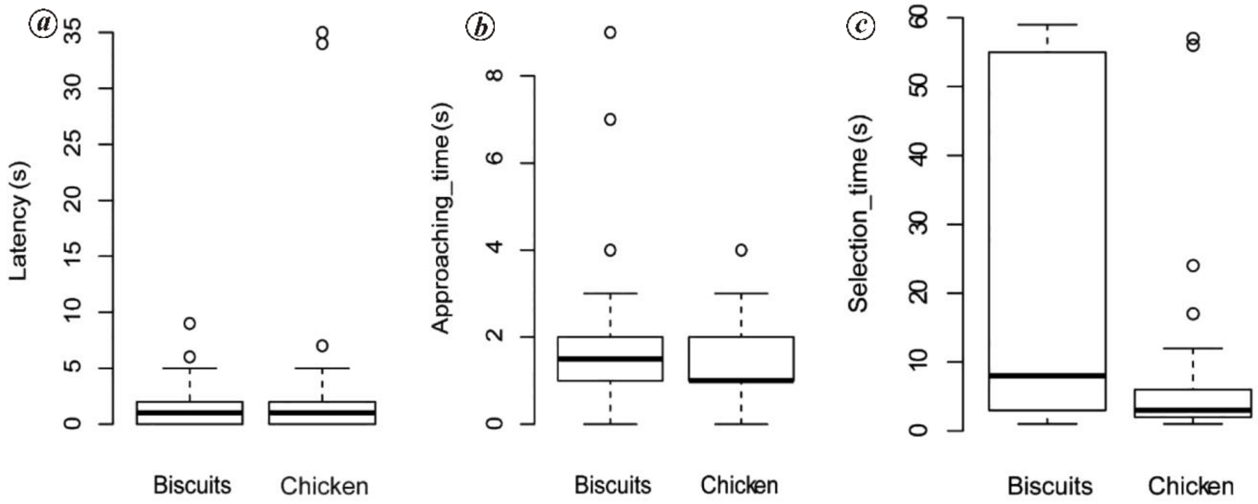

Figure 3. Box and whisker plots showing comparisons across biscuit and chicken options for (***a***) latency, (***b***) approaching time and (***c***) selection time.

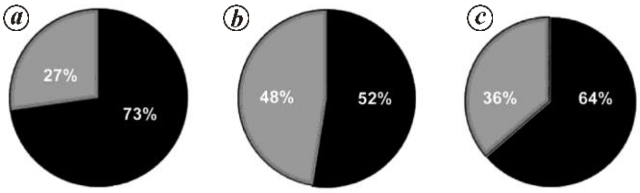

Figure 4. Pie charts showing comparison of selections between (***a***) 4B (grey) vs 4C (black), (***b***) 1C (grey) vs 4B (black) and (***c***) 4spC (grey) vs 4stC (black).

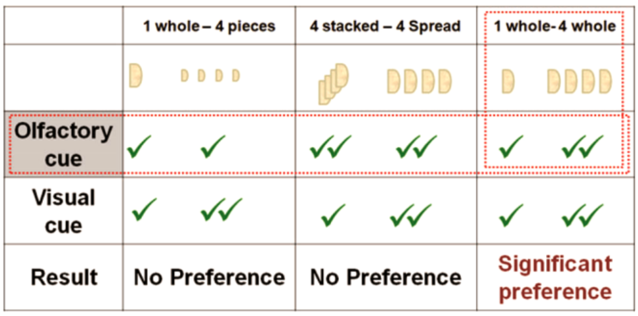

Figure 5. Schematic summarizing the comparison of preference in three categories and revealing that olfactory cues make a significant difference to the decision-making process of dogs.

present study, we found that the dogs use a 'relative quantity' judgement and not a 'relative numerousness' one. They made a clear choice only when four pieces of chicken were provided against a single piece of the same. In all other cases, they appeared to choose randomly. Since they are scavengers, dogs are used to feeding on carbohydrate-rich food, though the preferred option is meat[25,26]. This is supported by our results, as the dogs clearly showed specific selection of an option, whether the two options were chicken or biscuit, though they took a longer time to make a selection when biscuits were provided and ended up not discriminating between a single biscuit and four biscuits. The results from set-2 trials indicate that the counting ability, if present, is context-dependent. In order to understand this cognitive ability better, we designed the set-2 trials with options skewed in the context of food preference. Thus, the study indicates that free-ranging dogs seem to differentiate on the basis of less and more, rather than few and many. However, it cannot be determined if the dogs can distinguish between the number of units as such, but they clearly make a distinction on the basis of amount perceived. This differentiation seems to be context-dependent, based on preference. The differentiation between amounts of food offered is seen only when a preferred food type is weighed over a non-preferred food type, or the proportion of preferred food type is skewed across the two options. The dogs have preferentially used olfactory cues over visual cues in their decision-making. Previous studies from our laboratory have also shown that dogs use their strong power of olfaction for making distinctions between food options offered[22].

Anthropomorphism based on simple intuition dates back to the days of Darwin. In the second and third chapters of the *Descent of Man and Selection in Relation to Sex*, Darwin[27] outlines procedures for comparing 'mental powers' of non-human model organisms to humans. Much later, experiments to test these claims were conducted by Thorndike and his contemporaries[28,29]. Cognitive abilities when studied in non-human systems, are often considered synonymous with the ability to learn and this learning ability has often been used to define intelligence in non-human model organisms[30]. Numerical cognition is a widely used proxy measure for the intelligence of an animal[31]. Learning–intelligence hierarchy has eight levels, where succeeding to a higher level requires mastering of the lower level. This study suggests that free-ranging dogs are at level 5: concurrent discrimination learning (learning to assess stimulus – response operant units in parallel), of this hierarchy[30]. A test for this level should offer the animal two parallel sets, and the animal should be able to discriminate between them. Also, a trial-unique or first-trial-only requirement should be fulfiled in order to eliminate chances of rote-learning, wherein an animal can learn to choose a particular option associated with certain reinforcers. The protocol used in this study is thus ideal for the test and thus places free-ranging dogs at level 5 of this hierarchy. However, we still cannot ascertain if this is the highest 'level of intelligence' that the dogs can attain.

Numerosity, in principle, comes by counting or sequentially adding up units, and is more accurate compared to quantity estimation, which is volume-based and is more of an approximation. This study does not provide any conclusive result of a pre-existing or learned number system in the minds of dogs. It gives us more of an insight into their way of looking at the world, or rather, their own survival, when it comes to food rewards. Also, the role of context is interesting, as they do not seem to perform above random chance when offered a non-preferred food type. Although dogs are primarily scavengers and are expected to go for 'more' amount whenever food is concerned, yet we do not see such a bias when it is a non-preferred food type. Also, the role of their strong sense of olfaction in the decision-making process suggests that more than a volume-based visual discrimination, dogs value a smell-based olfactory discrimination while making decisions. This further strengthens previous studies which indicate that selection of proteins against carbohydrates offered is a 'rule of thumb' for these scavengers[22,26].

No study is devoid of any limitations, and there is no sample size good enough to test for cognitive ability. We cannot conclude if the dogs process the two options as 'one' and 'three added to one equals four', or simply as 'one' and 'many', due to lack of testing the possible ratios between these two numbers, namely 1 versus 2, 1 versus 3, 2 versus 3 and 2 versus 4. Thus, making a conclusion in the context of Weber's law is also not possible. Rote learning was definitely avoided in this study because no dog was tested more than once, food was not used as a positive reinforcement for the task (a food reward was received upon choosing either of the options), and no familiarization step was included before the actual test. Also, since the study was conducted on free-ranging dogs, biases due to previous history did not have any role to play. It has been suggested that items or units up to four can be discriminated upon even by pattern recognition, and actual counting may not be required[32]. The present study does not include any control for this. However, it clearly indicates that even if subitizing (counting by pattern recognition) was involved, discrimination was made on the basis of context.

The evolution of quantity discrimination may have been facilitated in social animals like dogs, due to real-life situations like inter-group conflicts or other challenges posed by their physical environment[17]. However, the present study subjects them to a choice-based task and we are unable to conclusively state if such quantity discrimination may exist in real-life situations. For a clearer idea of the discrimination made (numerical judgment or quantity judgement), a real-life situation study would be more apt. Both pack dogs and wolves have been shown to appropriately adjust their behaviour in inter-group conflicts, depending upon the opponent group size compared to the self-group size[33,34]. Another relevant real-life situation where keeping track of numbers may be necessary is for a mother to be aware of how many pups she has. No studies on any animal regarding monitoring of offspring have been conducted so far.

To summarize, the present study aims to understand quantity discrimination and not numerical discrimination ability of free-ranging dogs. We conclude that these dogs, which are efficient scavengers, use their strong sense of olfaction to make a decision between options offered in a two-way choice-based task. The selection indicates that the decision is made on the basis of less or more and not few or many, and is context-dependant, or rather, preference-dependant.

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