G Model
YLMOT-1398; No. of Pages 11
ARTICLE IN PRESS
Learning and Motivation xxx (2013) xxx–xxx
Contents lists available at SciVerse ScienceDirect
Learning and Motivation
journal homepage: www.elsevier.com/locate/l&m

Can dogs count?☆

Krista Macpherson*, William A. Roberts

University of Western Ontario, Canada

ARTICLE INFO

Article history:
Received 30 October 2012
Received in revised form 3 April 2013
Available online xxx

Keywords:
Dogs
Canine cognition
Counting
Numerical discrimination
Weber's law

ABSTRACT

Numerical competencies have been thoroughly examined in several species, yet relatively few studies have examined such processes in the domestic dog. In an initial experiment, procedures from numerical studies of chimpanzees (Beran, 2001; Beran & Beran, 2004) were adapted for use with 27 domestic dogs. Subjects in these experiments watched as different quantities of food were sequentially dropped into each of two bowls. The subjects were then allowed to select and consume the contents of one of the bowls. Although dogs excelled in a 1 vs 0 condition, their performance failed to significantly surpass chance across all other ratios. In a second experiment with a single subject (a rough collie named Sedona), the procedure was revised so that non-food stimuli were presented simultaneously to the dog on two magnet boards. If Sedona chose the board with the majority of the items, she was rewarded with a piece of food hidden underneath the board. If she made an incorrect choice, she received no reinforcement. Interestingly, Sedona's performance far exceeded that of the dogs in Experiment 1. Implications of these findings for the study of domestic dogs are discussed.

As humans we use number in almost every facet of our lives – we count how much money we have, check the temperature before we go outside, and look at our watches for the time. Numerosity is also an important function for non-human animals in their day to day existence – knowing how much food is available, how many offspring one has, or how many predators are approaching may all very well be useful survival skills. Precise counting and arithmetic as we know them are the result of language and culture – thus, these are uniquely human skills. There exists among adult humans, pre-verbal human infants, and non-human animals, however, an evolutionarily more primitive system of numerical discrimination, the approximate number system (ANS; Merritt, DeWind, & Brannon, 2012). According to the ANS, number is represented internally on a continuous, linear number line, which allows both humans and non-human animals alike to discriminate approximate magnitudes. Even human tribes with no formal system or language to represent number (e.g., the Pirahã and the Mundurukú) are able to discriminate numerosity using the ANS (Gordon, 2004; Pica, Lemer, Izard, & Dehaene, 2004). Number only becomes a discreet representation in human language when number symbols become mapped onto these approximate magnitudes through learning during childhood (Gallistel & Gelman, 1992). It is from this shared and primitive system that number symbols and the more precise use of number that is typical of adult humans has presumably risen.

Cardinality, ordinality and the internal representation of number

Number takes three forms – cardinal, ordinal, and nominal numbers. Cardinality refers to the elements of a set, and essentially asks the question "how many". Ordinality refers to the rank of an item (e.g., fourth place). Nominality concerns

☆ This research was supported by a Discovery Grant from the Natural Sciences and Engineering Research Council of Canada.
* Corresponding author at: Department of Psychology, University of Western Ontario, London, Ontario N6A 5C2, Canada.
E-mail address: kmacphe3@uwo.ca (K. Macpherson).

0023-9690/$ – see front matter © 2013 Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.lmot.2013.04.002

assigned numbers (e.g., the number an athlete wears on his jersey) and is therefore a uniquely human practice. Studies of numerosity in non-human animals are thus concerned exclusively with cardinal and ordinal number.

One of the hallmarks of the approximate system is that it obeys Weber's law. Weber's law states that the change in stimulus intensity needed for an organism to detect a change is a constant proportion of the original stimulus intensity, rather than a constant amount. Two effects that are seen as a result of this are the *distance* effect and the *magnitude* effect. The distance effect maintains that the greater the distance between two numbers, the easier they will be to discriminate (9 vs 1 will be easier to discriminate than 3 vs 1). The magnitude effect is the common finding that when distance is held constant, larger numbers are harder to discriminate than smaller numbers (2 vs 1 is easier to discriminate than 9 vs 8).

Ratio effects in accordance with Weber's law have clearly been demonstrated with pigeons. Using an operant conditioning chamber, Roberts (2010) showed pigeons three different combinations of red and green light flashes, using ratios of 2 vs 1, 3 vs 2, and 4 vs 2. The use of these particular ratios was important because the distance between numbers is 1 for 2 vs 1 and 3 vs 2, but increases to 2 for 4 vs 2. The ratio between numbers, on the other hand, was equal for 2 vs 1 and 4 vs 2, but smaller for 3 vs 2. If distance was controlling the performance of the pigeons, then it should have been found that 4 vs 2 was most easily discriminated, while 2 vs 1 and 3 vs 2 were harder but equally discriminable. Instead, it was found that 2 vs 1 and 4 vs 2 were equally discriminable, while 3 vs 2 was significantly more difficult to discriminate. This finding suggests that ratio, not distance, was controlling the performance of the birds.

One major issue with regards to number is whether it is represented by the ANS and/or by an object file system (Brannon, 2006; Carey, 1998; Feigenson, Dehaene, & Spelke, 2004). The ANS maintains that numbers are represented internally and continuously as an approximate magnitude on a number line. There is no upper limit to the approximate number system, but it does become systematically less precise as number increases. While the analogue magnitude system is generally an accepted account of numerical representation, the object file system is more controversial. The object file system (sometimes referred to as "subitizing") deals only with small numbers, specifically numbers 1–4. These numbers are thought to be mapped discreetly in a one-to-one represention, making them instantly accessible. For example, if subjects are shown four dots on a screen, they do not need to systematically count the dots because they will immediately recognize that there are four dots.

In support of the object file system, Hauser, Carey, and Hauser (2000) found that wild, untrained monkeys were able to discriminate and successfully choose a larger number of food items over a smaller number of food items. Over 200 semi-free-ranging rhesus monkeys watched as experimenters placed pieces of apple into each of two containers. The experiments then walked away so that the monkeys could approach the containers. When the containers contained 1 vs 2, 2 vs 3, 3 vs 4 or 3 vs 5 slices of apple, the monkeys chose the container with the greater quantity of food. Interestingly, however, when the items exceeded the number four (4 vs 5, 4 vs 6, 4 vs 8, or 3 vs 8) the monkeys were unable to reliably choose the container with the most food. Hauser et al. suggested that the breakdown in performance of the monkeys when the number exceeded four items is evidence that the monkeys were using a spontaneous number system (i.e., the object file system) as opposed to an analogue magnitude system in order to solve the problem.

In subsequent laboratory studies, Beran and colleagues (Beran, 2001; Beran & Beran, 2004) conducted experiments analogous to those of Hauser et al. (2000), in which chimps watched as an experimenter sequentially dropped pieces of food (M&Ms or pieces of fruit), one-by-one, into each of two bowls. The chimp was then allowed to choose one of the two bowls and consume its contents. In this laboratory task, chimps discriminated magnitude well beyond 4 items, and up to 10 items. The most persuasive argument against the use of an object file system is that even with numbers 1–4, both humans and non-human animals demonstrate the ratio-effects that are the signature of the ANS (Beran & Rumbaugh, 2001; Beran, Taglialatela, Flemming, James, & Washburn, 2006). If the one-to-one representation suggested by the object file system were in fact being used, then these ratio effects should not be seen for the numbers 1–4.

A major criticism of laboratory studies with non-human animals is that with extensive training and a large number of trials, the subjects may simply be learning the correct response to a problem associatively, rather than engaging in cognitive processing. Brannon and Terrace (1998) controlled this issue in a study of numerical discrimination by monkeys. In this ordinal task, two monkeys were first trained to order arrays of 1–4 items in ascending order. Unlike the Beran (Beran, 2001; Beran & Beran, 2004) studies, which used sequential presentation, these items were presented simultaneously, on a computer screen. Importantly, as a control for non-numerical cues, the items were varied in size, shape, and color. The monkeys were later tested, without reward, on novel pairs of stimuli from arrays of 5–9 items. Both monkeys were able to spontaneously order the new values, which suggests not only that their numerical ability was not the result of extensive laboratory training, but also that an analogue magnitude system was being employed by the monkeys. Similar findings have also recently been found with pigeons (Scarf, Hayne, & Columbo, 2012). In another study, Cantlon and Brannon (2006) trained monkeys to order pairs of numerical stimuli with the values of 1–9. Once the monkeys learned to order these values, they were introduced to pairs of novel displays of 10, 15, 20 and 30 items. Once again, monkeys were able to spontaneously order the novel values, suggesting that there is no known upper limit on the numerical capacity of these animals.

Evidence from neuroscience

Evidence from single cell recordings has implicated the intraparietal sulcus (IPS) as the primary brain structure involved in numerical processing. Although it was originally thought that the IPS might contain a specified number module, evidence now suggests that the IPS serves a "patchwork" of different functions (Ansari, 2008). The prefrontal cortex (PFC) is also