



Bears ‘count’ too: quantity estimation and comparison in black bears, *Ursus americanus*

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ARTICLE INFO

Article history:

Received 10 March 2012
Initial acceptance 23 April 2012
Final acceptance 27 April 2012
Available online 4 June 2012
MS. number: A12-00195R

Keywords:

area
bear
number
quantity estimation
ratio
Ursus americanus

Studies of bear cognition are notably missing from the comparative record despite bears' large relative brain size and interesting status as generalist carnivores facing complex foraging challenges, but lacking complex social structures. We investigated the numerical abilities of three American black bears, *Ursus americanus*, by presenting discrimination tasks on a touch-screen computer. One bear chose the larger of two arrays of dot stimuli, while two bears chose the smaller array of dots. On some trials, the relative number of dots was congruent with the relative total area of the two arrays. On other trials, number of dots was incongruent with area. All of the bears were above chance on trials of both types with static dots. Despite encountering greater difficulty with dots that moved within the arrays, one bear was able to discriminate numerically larger arrays of moving dots, and a subset of moving dots from within the larger array, even when area and number were incongruent. Thus, although the bears used area as a cue to guide their responses, they were also able to use number as a cue. The pattern of performance was similar to that found previously with monkeys, and suggests that bears may also show other forms of sophisticated quantitative abilities.

The Association for the Study of Animal Behaviour. Published by Elsevier Ltd.

Given that bears have the largest relative brain size of any carnivore (Gittleman 1986) even in comparison to other social species such as canines, about which there is a recent explosion of research (Miklósi et al. 2004; Hare 2007; Kubinyi et al. 2007), it is surprising that there are few published reports of their cognitive abilities. Other than reports on visual and spatial abilities (Bacon & Burghardt 1976; Tarou 2003; Kelling et al. 2006; Dungi et al. 2008; Perdue et al. 2011) and tool use (Bentley-Condit & Smith 2010; Deecke 2012) nothing is known of their cognitive traits in comparison to social species such as corvids (Emery & Clayton 2004; Seed et al. 2009), other large-brained mammals, such as primates (Tomasello & Call 1997; Rosati et al. 2010), and other carnivores, such as canines (Miklósi et al. 2004; Hare 2007; Kubinyi et al. 2007). This is a serious shortcoming in comparative psychology, and remedying this shortcoming could allow for better tests of the social intelligence (Jolly 1966; Humphrey 1976) and foraging hypotheses (Milton 1981, 1988). For instance, demonstrating that a nonsocial mammal that faces significant foraging challenges exhibits the same sorts of cognitive abilities as more social species within the same order may

indicate that adaptive problems faced in the physical environment, such as with foraging, is a better predictor of these kinds of cognitive traits, than is social living.

There are many examples of nonsocial animals that face significant foraging problems and demonstrate impressive cognitive skills, such as tool use and observational learning. For example, octopi and cuttlefish have the capacity to make conditional discriminations (Hvorecny et al. 2007; Ikeda 2009). However, although these species also exhibit problem-solving behaviour similar to that of several vertebrate species, their strategies sometimes demonstrate fixed behavioural patterns, rather than significant behavioural flexibility (Fiorito et al. 1998; but also see Mather 2006). Interestingly, Mather (2006) assumed behavioural flexibility in part based on flexible prey choice, and this idea suggests that bears make an interesting test case for assessing such flexibility because bears show flexibility in their diet (Gittleman 1986). Comparisons of closely related species, such as bears, to other carnivores that vary in their sociality and feeding regime, would be vastly informative with regard to hypotheses about the relative importance of sociality versus foraging demands. Unfortunately, the data with regard to cognitive abilities in carnivores, particularly in ursines and felines, is still too scarce to allow for many direct comparisons.

Clearly, however, it is useful, not only to make comparisons between species that are more closely related, as in the order Carnivora, but also to those species that are more distantly related,

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as with primates. Researchers can make inferences about when in a species' evolutionary history a trait may have been most likely to emerge by examining the presence or absence of such traits in species both closely and distantly related. Of course, such inferences must be made cautiously with consideration to the possibility of convergent evolutionary processes. One can look for convergence by examining differences in species' behavioural ecologies, such as arboreal versus terrestrial lifestyles, different mating strategies, home range size (Perdue et al. 2011) and distribution of food resources (Milton 1981). By doing so we can best determine which selective pressures are most likely to have given rise to different cognitive abilities, such as spatial memory (Tarou 2003; Perdue et al. 2011; Zamisch & Vonk, *in press*), concept formation (J. Vonk, S. E. Jett & K. W. Mosteller, unpublished data) and social cognition (Hare et al. 2002; Miklósi et al. 2004).

One well-studied area in comparative cognition is quantity estimation by nonhumans. Many species are capable of relative numerosity judgments (gorillas, *Gorilla gorilla*: Anderson et al. 2005; chimpanzees, *Pan troglodytes*: Boysen & Berntson 1995; Boysen et al. 1999; Beran 2001; rhesus macaques, *Macaca mulatta*: Brannon & Terrace 2000; Brannon et al. 2006; Cantlon & Brannon 2006; Beran 2007, 2008; capuchins: Judge et al. 2005; Beran 2008; lemurs: Santos et al. 2005; squirrel monkeys: Thomas & Chase 1980; dolphins: Jaakkola et al. 2005; Kilian et al. 2003; elephants: B. M. Perdue, C. F. Talbot, A. Stone & M. J. Beran, unpublished data; birds: Roberts & Mitchell 1994; Emmerton et al. 1997; Emmerton 1998; Pepperberg 2006; amphibians: Uller et al. 2003; fish: Agrillo et al. 2009; Gomez-Laplaza & Gerlai 2011). That is, they are able to choose among sets of items on the basis of the quantities or even numbers of items in those sets.

In some cases, food items are the stimuli to be discriminated, and here it is natural for animals to 'go for more' if they can. For example, chimpanzees will select the greater number of food items (e.g. Beran & Beran 2004), and salamanders will move towards larger numbers of prey items (Uller et al. 2003). In other cases, however, nonedible items are presented for comparison. For example, fish (Agrillo et al. 2009; Gomez-Laplaza & Gerlai 2011) have been tested for their approach to a larger group of conspecifics. Sometimes, totally arbitrary stimuli are used, presumably because those stimuli release subjects from prepotent responding as would occur to food items or other naturalistic stimuli. For example, primate and bird species are presented with two arrays of dots on a touch-screen computer, with one array containing a greater number of dots (Emmerton 1998; Beran 2007, 2008) and are required to choose the larger array. Alternatively, they may be required to arrange dot stimuli in ascending or descending order (Brannon & Terrace 2000; Brannon et al. 2006; Cantlon & Brannon 2006). The use of arbitrary stimuli such as dots allows the researcher to control factors such as size of the stimuli and area covered by the stimuli in relation to the background. By controlling factors such as size, the researcher is able to calculate the ratio of area and number between arrays and assess which cues the animal is using to make the discrimination. However, only social species have been tested in paradigms carefully controlling factors such as dot size, ratio, area and movement of the stimuli (Brannon & Terrace 2000; Brannon et al. 2006; Cantlon & Brannon 2006; Beran 2008). Therefore, it may often be the case that these species can estimate the relative size or amount of some commodity but are not necessarily enumerating the specific items.

Some studies indicate that numerical estimation in nonhuman primate species may be more akin to magnitude estimation than true counting. The performance of both rhesus monkeys and capuchins declines with increased ratio between the quantity in two sets in tasks presenting two arrays of dots that vary in number, as predicted by Weber's law, which states that the size of a just noticeable difference in stimulus intensity is a constant proportion

of the original stimulus magnitude (Brannon & Terrace 2000; Brannon et al. 2006; Cantlon & Brannon 2006; Beran 2008). For instance, discriminating between arrays of three dots and six dots is easier than discriminating between arrays of three dots and four dots. As the ratios increase, the difference between the two arrays is smaller, making it more difficult to discriminate the arrays on a perceptual basis. However, studies also show that such tasks tap into numerical abilities as monkeys' performance remains high when the amount or area is not confounded with number, even when enumerating subsets within moving arrays (e.g. Beran 2008). Careful control of such nonnumerical factors can indicate whether species are capable of tracking and individuating items of a set, such as members of their group, and using number to do so versus some other stimulus property. Thus, there is reason to speculate that this skill might have emerged in particular in social species, such as primates, cetaceans and social birds such as corvids and parrots (Pepperberg 2006). However, it is possible that this is a more evolutionarily ancient capacity that serves as a foundation of numerical cognition and may be shared among other large-brained species that exhibit numerical abilities. One working hypothesis is that animals that forage over large home ranges must evolve the ability to discriminate quantities of items, such as foods, to assist them in choices regarding relative costs and benefits of travel time and energy payoffs. However, one possibility is that they are very good at assessing quantity or magnitude (approximate amount) for static items, but they do not need to assess numerosity (exact number of items), and, in particular, have not evolved the capacity for enumerating dynamic stimuli. We test this possibility for the first time.

Here, three American black bears chose larger or smaller arrays of static and moving dots, showing effects of ratio and area that made their performance quite comparable to that of better-studied social species. One bear was able to choose a smaller subset from within a larger array of moving dots, even when area was not confounded with number and only number operated as a valid cue to the correct choice. These results from a nonsocial, large-brained mammal on both static and moving arrays, controlling for area and number, indicate that group living is not a prerequisite for the capacity to make numerosity judgments and even to enumerate subsets of moving stimuli.

METHODS

Subjects

Three captive adult American black bear siblings (one female and two males) were tested. The bears had previously participated in studies of cognitive dissonance (West et al. 2010), spatial memory (Zamisch & Vonk, *in press*) and concept formation (J. Vonk, S. E. Jett & K. W. Mosteller, unpublished data), although they had not previously been tested on tasks assessing quantity estimation or numerosity. The research took place in an off-exhibit area of the bears' enclosure at the Mobile Zoo in Wilmer, Alabama, U.S.A. Testing of subjects complied with the Institutional Animal Care and Use Committee of the University of Southern Mississippi (IACUC approval number 06091401). The experiments provided a form of enrichment for the subjects and did not present any risks or adverse effects. Housing and maintenance of the bears at the Mobile Zoo complied with regulations of the U.S. Department of Agriculture.

Materials

The experimental apparatus consisted of a durable Panasonic Toughbook laptop computer and a 19-inch, Vartech Armorall, Capacitive, touch-screen monitor welded to the front of a rolling

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