Cognition 125 (2012) 219–232

Contents lists available at SciVerse ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Grey parrot number acquisition: The inference of cardinal value from ordinal position on the numeral list

Irene M. Pepperberg [a,b,*], Susan Carey [a]

[a] Department of Psychology, Harvard University, United States
[b] Department of Psychology, Brandeis University, United States

ARTICLE INFO

Article history:
Received 4 September 2011
Revised 24 June 2012
Accepted 4 July 2012
Available online 9 August 2012

Keywords:
Animal cognition
Parrot cognition
Nonhuman numerical competence
Successor function
Parrot number acquisition

ABSTRACT

A Grey parrot (*Psittacus erithacus*) had previously been taught to use English count words ("one" through "sih" [six]) to label sets of one to six individual items (Pepperberg, 1994). He had also been taught to use the same count words to label the Arabic numerals 1 through 6. Without training, he inferred the relationship between the Arabic numerals and the sets of objects (Pepperberg, 2006b). In the present study, he was then trained to label vocally the Arabic numerals 7 and 8 ("sih-none", "eight", respectively) and to order these Arabic numerals with respect to the numeral 6. He subsequently inferred the ordinality of 7 and 8 with respect to the smaller numerals and he inferred use of the appropriate label for the cardinal values of seven and eight items. These data suggest that he constructed the cardinal meanings of "seven" ("sih–none") and "eight" from his knowledge of the cardinal meanings of one through six, together with the place of "seven" ("sih–none") and "eight" in the ordered count list.

1. Introduction

Nonhumans mostly draw on two distinct systems of mental symbols to represent number (see Carey (2009), Dehaene (2009), Gallistel and Gelman (2005) for reviews). Symbols in one system (the analog magnitude system) are mental magnitudes that are linear or logarithmic functions of the cardinal values of sets of items, and support computations of numerical equivalence and order, addition, subtraction, and ratios. But analog magnitude symbols only approximate the number of items in a set, are subject to Weber's law, and thus do not represent exact cardinality. A second system represents number only implicitly, with no mental symbols for cardinal values *per se*. Mental models in working memory are created for small sets of items, with one symbol for each item; these models also support computations of numerical equivalence and order, and addition and subtraction, based on 1–1 correspondence. This parallel individuation system cannot capture, even implicitly, any number beyond working memory limits (~4).

To overcome limits of these evolved systems, humans invented representations using external symbols. Tally systems (notches on a stick or clay tablet, beads on a string) represent cardinal values of sets of individuals via 1–1 correspondence, using external symbols to transcend limits of working memory. The verbal numeral list, deployed according to Gallistel and Gelman's (1992) "counting principles" (CP), represents exact cardinal values for every numeral in the list. Counting principles state: numerals must be applied in order to items in a set to be enumerated, must be applied in 1–1 correspondence, and the last numeral in a count represents a set's cardinal value. No evidence exists for mental representations of exact cardinal values of sets >4 by adult humans in cultures

* Corresponding author at: Department of Psychology, Wm. James Hall, Harvard University, 33 Kirkland Street, Cambridge, MA 02138, United States. Tel.: +1 617 495 2852.

E-mail addresses: impepper@media.mit.edu, impepper@wjh.harvard.edu (I.M. Pepperberg).

0010-0277/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cognition.2012.07.003

lacking verbal numerals or a tally system (Frank, Everett, Fedorenko, & Gibson, 2008; Gordon, 2004; Pica & Lecompte, 2008), deaf adults lacking natural language input (Spaepen, Coppola, Spelke, Carey, & Goldin-Meadow, 2011), preverbal infants (e.g., Feigenson, Dehaene, & Spelke, 2004) or nonhumans (except, possibly, those taught explicit symbolic representations, see below).

CP acquisition is not easy (Carey, 2009; Fuson, 1988). For several years children assign cardinal meanings only to a subset of their known count list (Le Corre, Van de Walle, Brannon, & Carey, 2006; Wynn, 1990, 1992). Two-year-old English learners produce the count list, but assign exact cardinal meaning only to "one"; other numerals mean "some" or "plural". Some 9 months later, they learn "two"; other numerals are "more than two". A few months later they master "three", then "four". Only then do children *induce* the CP: that each successive numeral in the count list is exactly +1 than its predecessor. This induction separates them from subset-knowers (Sarnecka & Carey, 2008); they can now encode cardinal value expressed by any numeral in their count list (see Carey, 2009; Hurford, 1987; Klahr & Wallace, 1973 for general characterizations of the Quinian bootstrapping that underlies CP acquisition, as well as many other episodes of conceptual change [Carey, 2009]).

These facts raise two interrelated questions about nonhumans' number representations: (1) Are they *restricted* to analog magnitude representations and/or parallel individuation? (2) Is bootstrapping, dependent upon logical operations carried out on external symbols and the capacity to create mappings between distinct representational systems, uniquely human? If so, a new hypothesis would be introduced to (partially) account for humans' unique capacity for cultural knowledge construction. We explore these two questions by investigating whether a nonhuman can infer the cardinal value represented by a novel numerical symbol from its place in an ordered numeral list.

The bootstrapping process children use to perform this feat has several prerequisites. First, children must represent order in the numeral list. Second, they must represent cardinal values of the first numerals ("one, two, three, four"). Third, they must understand and represent that cardinal values of adjacent numeral pairs—"one–two", "two–three", "three–four"—each differ by exactly 1. Finally, they must induce that this pattern extends indefinitely–that cardinal values of *any* two adjacent numerals differ by 1. Nonhumans have demonstrated many, but not yet all, of these prerequisites.

First, nonhumans represent ordinal relations among arbitrary stimuli. Macaques can learn to order 3–7 random items (e.g., cup, tiger, chair, etc.; Chen, Swartz, & Terrace, 1997; Swartz, Chen, & Terrace, 2000; Terrace, Son, & Brannon, 2003). Chimpanzees (Matsuzawa, 2009), rhesus, and capuchins (e.g., Beran et al., 2008; Harris, Beran, & Washburn, 2007) acquire ordinal relations among Arabic digits "0" through "9" in the absence of knowledge of these symbols' cardinal values.

Second, animals can use the analog magnitude system, constrained by Weber's Law, to support numerical computations of more/less for sets of individuals (Dehaene, 2009). For example, macaques (Brannon & Terrace, 1998, 2000) and pigeons (Scarf, Hayne, & Colombo, 2011) learned the rule "touch in order of increasing numerosity" for sets of diverse items in order "set size 1, set size 2, set size 3, set size 4", generalized to new sets of 1–4 items, then to untrained sets of 5–9.

Third, nonhumans have mapped numerals to approximate quantities. Monkeys (e.g., Beran et al., 2008) learned to relate digits to corresponding sets of candies, but also possibly to hedonic value or reward probability. Later, taught two ordered lists—numerals or dot arrays rewarded by corresponding sets of candies, or one candy for choice of the larger array (Harris, Gulledge, Beran, & Washburn, 2010)—monkeys, without training, integrated two ordered lists trained separately in alternation, choosing the larger of two stimuli, one from each list (e.g., set of 5 dots, the digit "3"; see D'Amato and Colombo (1988) and Terrace et al. (2003) for similar data).

Finally, some nonhumans unequivocally map numerals to cardinal values of sets. Most notable are two apes, Matsuzawa's Ai and Boysen's Sheba, and our subject, a Grey parrot, Alex. The apes' training took years, proceeding piecemeal (Biro & Matsuzawa, 2001; Boysen, 1993; Boysen & Berntson, 1989; Boysen, Berntson, Shreyer, & Quigley, 1993; Matsuzawa, 1985; Matsuzawa, Itakura, & Tomonaga, 1991; Murofushi, 1997; Tomonaga & Matsuzawa, 2000). Thus, Ai first learned to touch the digit "1" when shown sets of one item versus two, then "2" was added to her symbolic repertoire, up to "9". Ordinality had to be trained separately, as was equating an item set to a given digit. Sheba was taught similarly, to "8". Children do not learn in this piecemeal fashion: Even "subset-knowers" order numerals of known cardinal value and facilely label sets with verbal numerals and construct sets to cardinal values specified by known numerals (Le Corre, Van de Walle, Brannon, & Carey, 2006). Eventually, apes mastered these abilities.

What representations supported these abilities? Human adults resolve analog magnitude representations in ratios of 7:8 or 8:9 (see Barth, Kanwisher, & Spelke, 2003; Halberda & Feigenson, 2008); possibly Ai, Sheba, and Alex mapped numerals to analog magnitudes. However, if enumerating sets under time pressure, Ai's reactions reflected a pattern of subitizing for sets of 1 to 3, then a time increase with additional items from 4 to 9, suggesting another mechanism. Sheba tapped items one at a time before touching the symbol for cardinality of that set. Such data are consistent with the suggestion that some representations drawing on 1–1 correspondence or counting underlie at least some of Ai's and Sheba's performance with large sets. But neither ape engaged in the bootstrapping process that underlies children's mastery of the counting principles. Neither showed savings in learning as successive numerals "5", "6", "7", etc. were added to her repertoire.

The parrot, Alex, also took several years to learn to quantify sets of 1–6 items with vocal English labels (Pepperberg, 1987, 1994). But unlike children and apes, he did not acquire number labels in order, first learning "three" and "four", then "five" and "two", lastly "six"