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Brief Report

Quantity representation in children and rhesus monkeys: Linear versus logarithmic scales

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Abstract

The performances of 4- and 5-year-olds and rhesus monkeys were compared using a computerized task for quantity assessment. Participants first learned two quantity anchor values and then responded to intermediate values by classifying them as similar to either the large anchor or the small anchor. Of primary interest was an assessment of where the point of subjective equality (PSE) occurred for each species across four different sets of anchors to determine whether the PSE occurred at the arithmetic mean or the geometric mean. Both species produced PSEs that were closer to the geometric mean for three of four anchor sets. This indicates that monkeys and children access either a logarithmic scale for quantity representation or a linear scale that is subject to scalar variability, both of which are consistent with Weber's law and representation of quantity that takes the form of analog magnitudes.

Keywords: Quantity judgments; Representational scale; Children; Monkeys; Bisection task

Introduction

The quantity discriminations made by many species are restricted in their accuracy on the basis of the ratio between those sets (e.g., Barth, Kanwisher, & Spelke, 2003; Beran, 2007; Beran, Taglialatela, Flemming, James, & Washburn, 2006; Brannon, Cantlon, & Terrace, 2006; Brannon & Terrace, 2000; Call, 2000; Cantlon & Brannon, 2006; Hunt-

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ley-Fenner, 2001). Comparisons with larger ratios (as determined by dividing the smaller quantity by the larger quantity) lead to lower performance levels even when the distance between sets is constant (e.g., 8 vs. 10 is more difficult than 2 vs. 4). This suggests that an analog magnitude system produces discriminable representations of sets, and this system is consistent with Weber's law, which states that discrimination of sets becomes more difficult for a fixed difference as the magnitude of those sets increases.

Evidence for discrimination performance being modulated by Weber's law comes from differing sources. One task, used primarily with nonhuman primates, involves judgments between two sets of items (e.g., Beran, 2004; Brannon & Terrace, 2000; Call, 2000; Cantlon & Brannon, 2006; Judge, Evans, & Vyas, 2005). This task also sometimes is used with human children (e.g., Brannon & Van de Walle, 2001; Feigenson, Carey, & Hauser, 2002). The second task is the bisection task that has been used extensively with rats and pigeons (e.g., Emmerton & Renner, 2006; Fetterman, 1993; Meck & Church, 1983; Roberts, 2005, 2006) and occasionally with nonhuman primates and human children (e.g., Beran, Smith, Redford, & Washburn, 2005; Droit-Volet, Clement, & Fayol, 2003; Jordan & Brannon, 2006a, 2006b). In the bisection task, two anchor values (e.g., smallest set size and largest set size) are established through training, and then a larger range of values, including intermediate values, is presented. This task provides an important assessment of how quantity is represented because one can establish the point of subjective equality (PSE) at which there is indifference between classifying a stimulus as similar to the small anchor or the large anchor.

Knowing where the PSE falls is important in discerning how quantity is represented (Roberts, 2005). One possibility is that these representations are linear. A second possibility is that the scale for representation is linear, but with an increase in the variability of the discrimination proceeding in step with increases in the magnitude of the quantity itself (i.e., scalar variability) (Gallistel & Gelman, 1992; Gibbon, 1977; Meck & Church, 1983). A third alternative is that these representations are logarithmic, so that differences between sets with larger magnitudes are more pronounced compared with smaller sets despite the fact that the actual quantitative differences themselves are identical and the variability of the discrimination is constant (Dehaene, 2003; Roberts, 2005). If the PSE falls near the arithmetic mean, this establishes that the scale is linear. If the PSE falls near the geometric mean (the square root of the product of the anchor values), the interpretation is slightly more complicated. This outcome may suggest that the representation is logarithmic, with larger values more compressed in their relative spacing compared with smaller values, although it also may reflect a linear scale in which the represented distance between each successive quantity is equal but the degree of generalization is scalar (Gibbon, 1977; Roberts, 2005).

To date, only two studies have been conducted with human children using the bisection task, with conflicting results. Droit-Volet and colleagues (2003) presented sequential sets of stimuli to 5- and 8-year-olds and found that the PSE fell near the arithmetic mean. Jordan and Brannon (2006a), however, presented 6-year-olds with static sets of stimuli using a variation of the matching-to-sample paradigm and found that PSEs for two different sets of anchors both were near the geometric mean, a finding that matched a similar test given to rhesus monkeys (Jordan & Brannon, 2006b). Thus, data from human children have offered conflicting evidence of where the PSE falls for bisection tasks. In addition, there are very few direct comparisons of the performances of children and nonhuman animals on the identical tasks designed to assess numerical or quantitative skills (but see Cantlon & Brannon, 2006; Jordan & Brannon, 2006a). Typically, data from nonhuman animals indicate that the PSE falls nearer the geometric mean (e.g., Emmerton & Renner, 2006),