Infants use different mechanisms to make small and large number ordinal judgments

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Previous research has shown indirectly that infants may use two different mechanisms—an object tracking system and an analog magnitude mechanism—to represent small (<4) and large (≥4) numbers of objects, respectively. The current study directly tested this hypothesis in an ordinal choice task by presenting 10- to 12-month-olds with a choice between different numbers of hidden food items. Infants reliably chose the larger amount when choosing between two exclusively small (1 vs. 2) or large (4 vs. 8) sets, but they performed at chance when one set was small and the other was large (2 vs. 4) even when the ratio between the sets was very favorable (2 vs. 8). The current findings support the two-mechanism hypothesis and, furthermore, suggest that the representations from the object tracking system and the analog magnitude mechanism are incommensurable.

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Introduction

Quantities like space, time, and number are basic aspects of our experience that reflect fundamental properties of the environment. For animals to successfully navigate and function in their environment, it is necessary that they represent behaviorally relevant quantitative information. The case of number is of particular interest to psychologists and cognitive scientists because it is abstract and, therefore, presents a unique challenge to the nonverbal organism. Historically, it was believed that language provided the only means by which an organism could represent abstract concepts. Despite this, there is a growing body of evidence suggesting that a wide variety of animal species (see Gallistel, 1990; Gallistel & Gelman, 2005, for reviews), as well as preverbal human infants, not only represent quantity information but also perform computations over these representations. For example,
preverbal infants discriminate numbers of visual (Brannon, Abbott, & Lutz, 2004; Xu & Spelke, 2000) and auditory (Lipton & Spelke, 2003; vanMarle & Wynn, 2009) stimuli, compute additions and subtractions over large sets (McCrink & Wynn, 2004), and compute ratios for sets of visual elements (McCrink & Wynn, 2007).

Similar to nonhuman animals, infants’ ability to represent number seems to depend on a representational mechanism that is shared across species, has evolved to represent quantities (e.g., duration, number, continuous spatial quantities such as surface area), and represents quantities as analog magnitudes (Cantlon, Platt, & Brannon, 2009; Feigenson, 2007; Gallistel, 2011; Gallistel & Gelman, 2005; Gibbon, 1977; Meck & Church, 1983; Walsh, 2003; cf. Casasanto, Fotakopoulou, & Boroditsky, 2010; Hauser & Spelke, 2004; Mix, Huttenlocher, & Levine, 2002). The signature property of this mechanism is that discrimination of represented quantities follows Weber’s law; it is the proportionate difference, rather than the absolute difference, between two quantities that determines their discriminability. Thus, it is easier to discriminate 8 from 16 (a 1:2 ratio) than to discriminate 16 from 24 (a 2:3 ratio), even though the absolute difference in both cases is exactly 8 units.

In addition to an analog magnitude mechanism, infants appear to use another mechanism—an object tracking system—under some conditions. The object tracking system was originally described in the literature on object-based visual attention to explain adults’ ability to simultaneously track small sets of visual objects (Kahneman, Treisman, & Gibbs, 1992; Pylyshyn & Storm, 1988; Scholl, 2001). The mechanism consists of a small number of indexes that “point” to objects out in the world, allowing the observer to keep track of their locations as they move and undergo occlusion. In contrast to the analog magnitude mechanism, the object tracking system is not a number mechanism per se. Instead, it represents number only implicitly. For example, a set of indexes can be matched to a visible (but previously occluded) set via a one-to-one correspondence operation, allowing discrepancies to be detected. The signature property of this mechanism is its limited capacity; one can track only as many objects as one has indexes, which in adults appears to be roughly 4.

Recent studies investigating this system have suggested that the capacity limit might not be strictly “object based” and that it may be a more general aspect reflecting the number of slots available in working memory (Halberda, Sires, & Feigenson, 2006; Wynn, Bloom, & Chiang, 2002; Zosh, Halberda, & Feigenson, 2011). In addition, recent studies using other paradigms (e.g., change detection, multiple object tracking) suggest that the capacity is quite flexible and interacts with object complexity. That is, the capacity limit is higher for sets of simple objects with few features than for sets of complex objects with multiple features (infants: Zosh & Feigenson, 2009; adults: Alvarez & Cavanagh, 2004; Alvarez & Franconeri, 2007). Nonetheless, for the current study, I refer to the “object tracking” system in its original conception, where an object-based capacity limit is considered a signature property of the system (e.g., Kahneman et al., 1992; Pylyshyn & Storm, 1988; Scholl, 2001).

Evidence for this mechanism in infants comes from work by Feigenson and colleagues (Feigenson & Carey, 2003; Feigenson, Carey, & Hauser, 2002; Feigenson, Carey, & Spelke, 2002) in which infants exhibit the set size signature believed to be indicative of the object tracking system. In one study, using a manual search procedure, 12- and 14-month-olds watched an experimenter hide some number of objects in an opaque box, watched her retrieve either all or just a subset of the objects, and then were allowed to reach into the box. Whenever the initial set was 3 or fewer, infants would reach reliably longer when a subset of objects remained in the box than when the entire set had been retrieved. However, there was no difference in search times when 4 items had been hidden regardless of how many the experimenter had retrieved (Feigenson & Carey, 2003).

Other studies, using the ordinal choice procedure, revealed the same set size signature (Feigenson & Carey, 2005; Feigenson, Carey, & Hauser, 2002). In them, 10- to 12-month-olds watched an experimenter hide different numbers of crackers in two different (opaque) cups. Once hidden, infants were allowed to choose one of the two cups. Because the hidden items were both desirable and edible, if infants could keep track of how many crackers went into each cup and mentally compare the amounts,

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1 We subscribe to this view, as opposed to more recent alternatives, because the initial evidence for a capacity limit in infants was found using objects and using the current procedure. Recent challenges to the strict capacity limit and the object-based nature of the representations derive from studies using different stimuli and paradigms as well as (often) different participant populations (i.e., adults and older infants).
they were expected to select the larger of the two quantities. The prediction was upheld, but only as long as there were 3 or fewer crackers in either cup. Infants reliably chose 2 over 1 and 3 over 2, but they chose randomly in comparisons of 3 vs. 4, 2 vs. 4, 3 vs. 6, and even 1 vs. 4, where the proportionate difference was highly favorable (Feigenson & Carey, 2005; Feigenson, Carey, & Hauser, 2002).

Feigenson and colleagues interpreted these data as showing that, in this task, infants are limited to representing small set sizes (no more than 3 items) and, accordingly, suggested that object tracking underlies infants’ performance. This type of discontinuity was further taken as evidence that infants may use these two different representational mechanisms—object indexes and analog magnitudes—to represent small and large numbers, respectively. Xu (2003) also forwarded this idea on the basis of looking time data showing that 6-month-olds successfully discriminated 4 from 8, but not 2 from 4, visual elements when continuous variables were controlled. Taken together with previous results showing that under the same conditions infants of that same age successfully discriminated 8 from 16 and 16 from 32 but not 1 from 2 visual elements (Xu, Spelke, & Goddard, 2005), these findings support the existence of the two mechanisms and further suggest that each mechanism exclusively represents sets within its preferred range. Importantly, infants’ failure to discriminate 1 from 2 in Xu and colleagues’ (2005) study is at odds with Feigenson, Carey, and Hauser’s (2002) finding that infants succeed in a 1 vs. 2 comparison. According to Xu and colleagues, infants do not discriminate 1 from 2 dots because the object tracking system registers individual objects but does not output a representation of the total number of objects in a set. In other words, there is no cardinal representation that infants could use to compare the number of items seen on one trial with the number of items seen on a subsequent trial. Another possible explanation for the difference is that continuous properties of the items were controlled in Xu (2003) and Xu and colleagues (2005) but were confounded with number in Feigenson, Carey, and Hauser (2002). Previous work has shown that infants fail to respond on the basis of number when continuous variables are controlled unless features of the objects in a set are contrasting (Feigenson, 2007) or individuation is otherwise emphasized (e.g., in a reaching task; Feigenson & Carey, 2003).

Recent work by Cordes and Brannon (2009) may shed some light on the discrepancy. Using similar dot displays as those used in Xu (2003) and Xu and colleagues (2005), with similar controls for continuous extent, Cordes and Brannon showed that 7-month-olds reliably discriminate small from large sets, but only when the ratio between the quantities is very large (1:4). Thus, they successfully discriminated 1 from 4 and 2 from 8 dots, but they failed to discriminate 2 from 4 or 3 from 6 dots. Cordes and Brannon took this pattern of results to indicate that, contrary to Xu (2003), the analog magnitude system represents both small and large numbers but that a larger ratio is required for discriminating sets that cross the set size boundary due to an increased ratio threshold, which when exceeded allows infants to use analog magnitudes, rather than object tracking representations, in the comparison procedure. On this view, although infants may use both systems to represent small sets, object tracking representations trump analog magnitude representations (because of their greater precision) unless (a) they cannot be used (i.e., when one set is small and the other is large) and (b) the threshold is exceeded. Although this explanation provides one possible explanation for Cordes and Brannon’s results, the authors acknowledged that their data cannot distinguish between their preferred threshold hypothesis and an alternative explanation—the noise hypothesis—in which the increased ratio required for discrimination is due to additional error in the analog magnitude representations as a result of a conversion process from initial object tracking representations into analog magnitudes prior to comparison.

The current study used a paradigm—the ordinal choice paradigm—that, on the basis of the set size signature findings described above (Feigenson & Carey, 2003, 2005; Feigenson, Carey, & Hauser, 2002), is believed to selectively recruit the object tracking mechanism and not the analog magnitude system. Importantly, however, the suggestion that analog magnitudes do not underlie performance in this task rests on evidence from comparisons in which one of the sets was small and the other was large (e.g., 2 vs. 4, 3 vs. 4, 3 vs. 6). Recent evidence from vanMarle and Wynn (2011) demonstrates that when both sets exceed the set size limit, infants do use analog magnitudes. In a control condition using the same procedures as those used here (and in Feigenson, Carey, & Hauser, 2002), 10- to 12-month-olds reliably chose the larger of two sets of food items when both quantities were in the large number range (5 vs. 10). This finding provided the first evidence that infants can use analog magnitudes in this task and raised the question of exactly what role the object tracking and analog magnitude mechanisms play in representing small and large sets.
Given the positive evidence that infants can choose the larger of two "large" sets in this paradigm, the current study was designed to test the hypothesis that the reason why infants failed with large numbers in previous studies is not due to a general inability to engage the analog magnitude mechanism but rather is due to the fact that the representations from the object tracking system (for small sets) and the analog magnitude mechanism (for large sets) are incommensurable, which disrupts infants' ability to compare small and large amounts and subsequently to judge which is larger.

Unlike Cordes and Brannon's (2009) study, which used static displays of dots with the entire set simultaneously visible, the current study tested infants' ability to determine the larger of two sets of real objects under conditions that should engage the object tracking mechanism. Although static, simultaneously available sets of two-dimensional visual elements might conceivably be represented by the object tracking mechanism, they do not provide the ideal input for the mechanism. Therefore, the use of real objects, moving through space and undergoing occlusion, was expected to provide the optimal conditions for the engagement of the object tracking mechanism. As such, this study provides a strong test of whether object tracking and analog magnitude representations are indeed incommensurable.

Four comparisons were tested (1 vs. 2, 2 vs. 4, 2 vs. 8, and 4 vs. 8). Infants were given a choice among exclusively small sets (1 vs. 2), exclusively large sets (4 vs. 8), and sets that lie on different sides of the set size boundary (2 vs. 4 and 2 vs. 8). The ages tested and the procedure were the same as those used in Feigenson, Carey, and Hauser (2002) and Feigenson and Carey (2005) so as to be comparable. Across the different comparison conditions, the only difference was the number of items in each set; the ratio between the quantities was equivalent (1:2) in all cases except for the 2 vs. 8 comparison in which the ratio was even more favorable (1:4). If infants use object indexes to represent small sets and use analog magnitudes to represent large sets, and if these representations defy comparison, then infants are expected to succeed with exclusively small and large sets and to perform at chance when the comparison involves one small and one large set even when the ratio is large (1:4) and highly discriminable.

**Method**

**Participants**

In total, 64 10- to 12-month-olds participated in the experiment, with 16 infants in each of four conditions. Half of the infants in each condition were female. Infants ranged in age from 9 months 13 days to 12 months 15 days (M = 10 months 27 days). An additional 31 infants2 were tested but excluded from the sample for failing to choose (23 infants), fussiness (2), making an unclear choice (2), parental interference (2), or experimenter error (2). All participants were recruited from the Columbia, Missouri, area in the U.S. Midwest. Infants' names were obtained via a commercial mailing list, and parents were contacted first by letter and then by phone. Infants received a small gift or $15 travel reimbursement. All parents whose infants participated signed a consent form prior to participation.

**Design**

Infants were randomly assigned to one of four test conditions (1 vs. 2, 2 vs. 4, 2 vs. 8, or 4 vs. 8). Thus, infants were asked to compare two small sets (1 vs. 2), two large sets (4 vs. 8), or one small and one large set (2 vs. 4 and 2 vs. 8).

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2 The number of infants excluded is greater than in many studies using this paradigm. It should be noted, however, that 14 of the 31 excluded infants were in the 1 vs. 2 condition (the first condition that was run) and that the remaining 17 infants were distributed roughly equally across the remaining three conditions (6, 6, and 5 infants for 2 vs. 4, 4 vs. 8, and 2 vs. 8, respectively). Of the 14 infants in the 1 vs. 2 condition, 13 were excluded for failure to choose. The reason for this high rate of dropout was due to using multiple presenters. After experiencing such high dropout rates, we returned to our previous practice in which only two or three research assistants were designated as presenters and collected all of data for the remaining conditions. This meant that these individuals were highly trained and comfortable in interacting with the infants in the context of the experiment, which helped to make the infants feel comfortable. The presenters were kept naive as to the purpose of the study, and reliability coding by a separate naive individual confirmed that their judgments were unbiased.
Following a short warm-up trial, infants received a single test trial in which they were given a choice between two hidden quantities of Cheerios (a popular breakfast cereal). The order in which the amounts were hidden (large first or small first) and the side on which the larger quantity was hidden (right or left) were counterbalanced across infants by randomly assigning them to one of four counterbalancing conditions: \( lg-R \) (large amount first, on the right), \( lg-L \) (large amount first, on the left), \( sm-R \) (small amount first, on the right), or \( sm-L \) (small amount first, on the left).

**Stimuli/apparatus**

Stimuli consisted of a green plastic bucket (16 cm high \( \times \) 16 cm in diameter) and a small toy duck that squeaked (9 cm wide \( \times \) 8 cm high), both of which were used in the warm-up trial, and two identical opaque red plastic cups (16 cm high \( \times \) 8.5 cm in diameter) into which the experimenter hid Cheerios (with each Cheerio, or “O”, being \( \sim \) 1 cm in diameter) during the test trial. Cheerios were used because they (a) are liked by infants, (b) are safe for infants, and (c) were used in vanMarle and Wynn’s (2011) successful large number comparison. In all four conditions, the experimenter dropped Cheerios from her hand one at a time into the two cups, first one amount and then the other. Infants only ever saw one O at a time. The quantities consisted of 1, 2, 4, and 8 Os.

**Procedure**

The procedure was designed to be as similar as possible to that used by Feigenson, Carey, and Hauser’s (2002) and consisted of two trials: warm-up and test. The parent sat on the floor approximately 6 feet from the experimenter holding the infant on their lap. Once in place, warm-up began when the experimenter brought out the toy duck and the bucket. The experimenter shook the bucket upside down and placed it on the floor (right-side up) and then squeaked the toy duck several times before hiding it in the container. The experimenter then verbally encouraged the infant to retrieve the toy. The infant was praised for retrieving the toy and asked to place it back into the container, which was subsequently withdrawn and hidden out of the sight of the infant. The test trial followed. The parent was asked to again seat the infant on their lap. The trial began with the experimenter bringing out the two plastic cups, with the open ends facing the infant. While the infant watched, the experimenter shook the cups upside down (to show that they were empty) and then placed them (right-side up) on the floor approximately 2 feet from herself (and 4 feet from the infant), and approximately 4 feet apart, so that they were equally spaced to the right and left of the infant.

Before hiding the test quantities, the experimenter modeled eating Cheerios for the infant. This was done to show that the items were edible, although all infants had reportedly eaten Cheerios before participation in the experiment. During the modeling phase of the trial, the experimenter poured 4 Os into her hand from a small plastic cup and then hid the cup behind her back. The experimenter then extended her hand (flattened so that the infant could see the Cheerios) and ate the Cheerios one at a time, commenting each time about how “yummy” the Cheerios were. Following this, the experimenter poured the first test quantity into her hand from a different small plastic cup and hid the cup behind her back. She then extended her arm over one of the cups and dropped the Cheerios in one at a time, being sure that the infant saw each O fall into the cup. The experimenter then poured the second quantity into her hand (hiding the small empty cup behind her back) and extended her arm over the second cup before dropping the second quantity in one O at a time. Once all of the Cheerios were hidden, the experimenter looked down into her lap (to avoid cuing the infant) and asked the parent to release the infant. If the infant failed to immediately move toward either of the cups, the experimenter verbally encouraged the infant to “find something to eat”. Verbal encouragement continued until the infant chose a cup and was equally enthusiastic regardless of the infant’s path of progress.

The dependent variable was whether infants chose the larger or smaller amount of food. The experimenter manually recorded which amount infants chose immediately following the test trial. Sessions were also videotaped to allow offline reviewing and reliability coding. Inclusion/exclusion criteria were the same as those used in Feigenson, Carey, and Hauser (2002). Infants were considered to have made a choice when they either (a) approached a cup and reached into it or (b) approached a cup and
Infants' performance differed across the four conditions. In the 1 vs. 2 and 4 vs. 8 conditions, infants reliably chose the larger amount (1 vs. 2: 13 of 16 infants, $p < .05$, one-tailed sign test; 4 vs. 8: 12 of 16 infants, $p < .05$). However, infants performed at chance in the 2 vs. 4 and 2 vs. 8 conditions (2 vs. 4: 7 of 16 infants chose the larger amount, $p > .05$; 2 vs. 8: 8 of 16 infants chose the larger amount, $p > .05$). See Fig. 1.

A two-tailed Fisher's exact test on the frequencies of large and small amount choices across the four conditions was marginally significant ($p = .07$). However, two separate two-tailed Fisher exact tests comparing large and small amount choices on the exclusive sets (1 vs. 2 and 4 vs. 8) and the mixed sets (2 vs. 4 and 2 vs. 8) were not significant (both $ps = 1$). Thus, performance did not differ for the small and large exclusive sets or for the close and far ratio mixed sets. Effects of side, order, and gender were tested separately for each condition. There were no effects of side or order of presentation ($ps > .20$, two-tailed sign test), nor did gender interact with choice, side, order, or Side × Order (all $ps > .32$, two-tailed Fisher exact tests).
Discussion

As predicted, when the two comparison amounts were exclusively small (1 vs. 2) or large (4 vs. 8), infants reliably chose the larger amount. However, when one of the amounts was small and the other was large (2 vs. 4 and 2 vs. 8), infants performed at chance even when the ratio between the quantities was highly discriminable (2 vs. 8). Note that the 2 vs. 8 failure essentially replicates Feigenson and Carey (2005) finding that infants fail in a 1 vs. 4 comparison. In addition, the 2 vs. 8 failure here cannot be explained by greater distraction or lengthy presentation times given that infants succeeded in the 4 vs. 8 comparison, and previous studies (Cheries, Mitroff, Wynn, & Scholl, 2008; Feigenson, Carey, & Hauser, 2002) have included explicit controls to rule out such alternative explanations. The fact that success with exclusive sets and failure with mixed sets was found in a single age group using the same procedure provides direct evidence that (a) infants use both mechanisms and (b) the output of the mechanisms is incommensurable.

In addition, infants' success in the 4 vs. 8 condition replicates the 5 vs. 10 result in vanMarle and Wynn (2011) and provides clear evidence that infants can and do use analog magnitudes in this task, at least to represent and compare large sets.

An obvious question to ask is why do infants appear unable to compare the amounts represented by these different mechanisms? Xu (2003) suggested that the difficulty lies in the nature of the representations output by each system. Specifically, analog magnitude representations contain information about the cardinal value of the represented set, whereas object tracking representations do not (Gallistel, 2007). Within the small number range, where both sets are represented by object tracking representations, infants presumably maintain representations consisting of one mental token for each object in the represented set, for example, [object] for the set consisting of just one object and [object object] for the set of two objects. When making the ordinal judgment, infants attempt to place the representations into one-to-one correspondence and, in doing so, detect that the latter set is larger than the former set. For exclusively large sets, the numerosity of the set is represented as a magnitude (which inherently denotes cardinality); thus, the infant is able to judge which is larger by comparing the sets on the basis of cardinality. However, when one set is small and the other is large, there is no basis for comparison. The object tracking representation for the small set cannot be put into one-to-one correspondence with the magnitude representation of the larger set; thus, the infant is prevented from making an ordinal judgment.

Given that Xu's work (Xu, 2003; Xu et al., 2005) failed to show that infants can successfully discriminate exclusively small sets (1 vs. 2) and sets that cross the set size boundary (2 vs. 4), her data do not directly support the claim that the two systems' representations are incommensurable. The current data, however, do provide direct evidence. If the infants were representing both small and large sets with analog magnitudes, they should have succeeded with the 2 vs. 4 and 2 vs. 8 comparisons. They did not, suggesting that they were using the object tracking system to represent small sets, as has been proposed in studies using similar stimuli and the same procedure (Feigenson, Carey, & Hauser's, 2002). In combination with the fact that they succeeded with large sets here (4 vs. 8) and in vanMarle and Wynn (2011) (5 vs. 10) and, therefore, were using analog magnitudes in those conditions (because the object tracking system is limited to representing only up to 3 objects in infants), the current study yields direct evidence that infants were using both mechanisms and, therefore, supports the claim that the representations of the two mechanisms cannot be compared by infants of the age tested here.

The pattern of results presented here is at odds with the findings presented in Cordes and Brannon (2009), where 7-month-olds successfully discriminated small from large sets when the ratio was highly discriminable (2 vs. 8). The primary difference between the two studies lies in the nature of the tasks. Whereas Cordes and Brannon used a habituation task using simultaneously presented two-dimensional sets of items, the current task used an ordinal choice procedure in which infants needed to track and compare sequentially hidden quantities of real objects. I argue that these differences compelled infants to use the object tracking system for small sets in the current task. Thus, the use of a task that promotes the engagement of the object tracking mechanism causes the object tracking representations to trump analog magnitude representations even when the ratio between the quantities is highly favorable. On this account, the threshold and noise hypotheses suggested by
Cordes and Brannon to explain infants’ success with 2 vs. 8 in their paradigm cannot be true in the general sense. If infants simply require some ratio threshold to be exceeded in order to allow analog magnitudes to dominate object tracking representations, then infants should have succeeded in the 2 vs. 8 comparison here. Similarly, if the larger ratio required in Cordes and Brannon’s study was due to added noise resulting from the conversion of object tracking representations into analog magnitudes, then infants should have made the conversion in this case and succeeded with 2 vs. 8. Instead, infants’ 2 vs. 8 failure in the current study suggests that in a task where the object tracking system is likely to be engaged, infants neither use analog magnitudes to represent small sets nor convert object tracking representations into analog magnitudes.

Alternatively, one could argue that the reason why infants succeeded in discriminating 2 vs. 8 in Cordes and Brannon (2009), but failed in the current study, was because the ordinal choice task imposes substantial demands on memory that are not required of infants in a habituation task. Thus, the threshold hypothesis might still be true, and infants may just require an even larger ratio difference in this more difficult task. However, this seems unlikely. If the considerable memory demands led to infants’ failure in the 2 vs. 8 choice task, then infants also should have failed in the 4 vs. 8 comparison where the memory demands were even greater. Therefore, infants’ clear success in that comparison (and with a 5 vs. 10 comparison; vanMarle & Wynn, 2011) argues against this alternative.

The current study does not address whether infants made ordinal judgments on the basis of numerosity or some continuous property of the sets such as summed surface area or volume. Feigenson, Carey, and Hauser (2002) showed that with small sets, infants actually make their choice on the basis of total amount of food. When given a choice between 1 huge cracker (volume $2^2$) and 2 tiny crackers (each with volume $1^2$), infants (wisely) chose the single large cracker, maximizing the amount of food obtained. Nonetheless, their performance was still limited by set size, indicating that the number of objects was also critical. Because the items used in the current study were also food items, it seems likely that infants here also based their judgments on total amount. But regardless of whether they made their choice on the basis of number of Cheerios or total amount of food, infants must have used analog magnitudes given that the number of individuals in each set clearly exceeded the capacity limit of the object tracking system. Indeed, ongoing studies are testing whether or not infants’ performance with large sets in this task exhibits the ratio signature and whether the Weber fraction for large numbers in this task maps on to previous studies using large numbers.

The current study leaves open several questions that would be fruitful avenues for future research. One is that it is not clear whether there are any circumstances in which infants could use analog magnitudes to represent small sets in this task. Future studies could manipulate the nature of the stimuli or context (e.g., using static displays or looking time) in order to determine what parameters are critical for the engagement of either or both mechanisms. In addition, it is unclear from the current study whether the representations from the two systems could ever be compared, for example, if the larger set exceeded the smaller by an enormous amount (e.g., 100 vs. 1). Relatedly, given that children and adults can compare small and large sets, one question is when this ability develops and what changes to allow such comparisons to be made effectively. Clearly, there are many questions that still need to be explored.

In conclusion, the pattern of results reported here suggests that infants engage both the object tracking system and the analog magnitude mechanism in the ordinal choice task. The mechanism used depends on the numerosity of the quantities being compared, with object indexes used to represent small sets (3 or fewer) and analog magnitudes used to represent large sets (4 or more). The central finding is not just that infants use both mechanisms in this task but also that the two mechanisms produce representations that are incommensurable, thereby preventing infants from making ordinal judgments between small and large sets. A better understanding of how the object tracking and analog magnitude systems interact early in development can not only inform our basic understanding of early numerical cognition but also may provide insight into what types of early learning experiences can promote the growth of numerical competence.

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