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Brief article

Enumeration of collective entities by 5-month-old infants

Karen Wynn[a,*], Paul Bloom[a], Wen-Chi Chiang[b]

[a]*Department of Psychology, Yale University, P.O. Box 208205, New Haven, CT 06520-8205, USA*
[b]*Department of Psychology, National Chung-Cheng University, 621 Chia-Yi, Taiwan, ROC*

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Abstract

Recent findings suggest that infants are capable of distinguishing between different numbers of objects, and of performing simple arithmetical operations. But there is debate over whether these abilities result from capacities dedicated to numerical cognition, or whether infants succeed in such experiments through more general, non-numerical capacities, such as sensitivity to perceptual features or mechanisms of object tracking. We report here a study showing that 5-month-olds can determine the number of *collective* entities – moving groups of items – when non-numerical perceptual factors such as contour length, area, density, and others are strictly controlled. This suggests both that infants can represent number per se, and that their grasp of number is not limited to the domain of objects.

Keywords: Enumeration; Collective entities; 5-month-old infants

1. Introduction

What is the nature of human infants' numerical knowledge? Infants can distinguish sets of different small numerosities. When visually habituated to displays of a given number (e.g. two) of items, they will subsequently look longer at displays containing a new number (e.g. three) than at new displays containing the habituated number (Antell & Keating, 1983; Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1983; Strauss & Curtis, 1981; van Loosbroek & Smitsman, 1992). Moreover, they can perform simple numerical computations, anticipating the numerical outcomes of physical operations such as the addition or removal of an object from a small array (Koechlin, Dehaene, & Mehler, 1997; Simon, Hespos, & Rochat, 1995; Uller, Carey, Huntley-Fenner, & Klatt, 1999;

* Corresponding author. Tel.: +1-203-436-1406; fax: +1-203-436-1915.
E-mail address: karen.wynn@yale.edu (K. Wynn).

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Wynn, 1992a, 1995). One proposal is that these abilities result from innate mental structures dedicated to representing and reasoning about number (Gallistel & Gelman, 1992; Wynn, 1992b, 1998).

Recently, however, some researchers have proposed that infants' performance on such tasks is better explained by appeal to cognitive capacities that are not specifically numerical. In some studies reporting numerical abilities in infants, non-numerical properties that correlate with number of objects, such as the 'contour length' of the display (i.e. the sum of the perceptual contours of the items in the display) or the total surface area of the items, were not adequately controlled for. It has been shown (Clearfield & Mix, 1999; Feigenson, Carey, & Spelke, 2002) that infants are sensitive to these non-numerical attributes, raising the possibility that infants' success in previous tasks is not due to numerical competence. Other researchers (Leslie, Xu, Tremoulet, & Scholl, 1998; Simon, 1997; Uller et al., 1999) have suggested that infants' performance in number discrimination tasks, numerical computation tasks, or both may reflect the operation of specialized mechanisms within visual cognition dedicated to the representation and tracking of individual objects within a scene (Kahneman, Treisman, & Gibbs, 1992), rather than a sensitivity to numerosity.

One way to address this issue is to investigate infants' capacity to enumerate entities that are not objects. Adults can enumerate any entities that we conceive of as distinct individuals, and hence we can count not only objects, but also parts, wholes, ideas, events, and so on. There is some evidence that infants too can enumerate at least some kinds of non-object entities, such as actions (Sharon & Wynn, 1998; Wynn, 1996) and sounds (Lipton & Spelke, 2001; Starkey, Spelke, & Gelman, 1990; but see also Mix, Huttenlocher, & Levine, 1997; Moore, Benenson, Reznick, Peterson, & Kagan, 1987). One type of non-object individual of particular interest is collective entities, such as a flock of birds or a school of fish. Previous studies suggest that young children can reason about the part–whole relations within familiar collections, and can learn words that refer to novel collective entities (Bloom & Kelemen, 1995; Callanan & Markman, 1982; Markman, Horton, & McLanahan, 1980), and that infants can represent and reason about a group of objects (Chiang & Wynn, 2000). Can infants construe a collective entity, consisting of multiple objects, as a unitary individual for enumeration purposes?

Collections differ from single objects in certain important ways. Unlike objects, collections violate the 'solidity principle' (two flocks of birds can pass through each other, and can occupy the same space at the same time, as when they all land together in a single tree), and they need not exist continuously in time or space (a flock of birds can disperse, and converge again at a later point) or maintain unique boundaries as they move through space (several flocks can merge together to become a single flock, and vice-versa).

From a psychological standpoint, not every group of objects is a natural or meaningful collection. The array of objects on one's desk, for instance, is usually seen as just that – an array of distinct objects, not a single collection. To be construed *as a collective entity*, the objects must share certain distinctive properties, such as behaving with a single goal (e.g. players on a football team), being created for a common purpose (e.g. a bikini), or undergoing common motion (e.g. a flock of birds). For instance, consider a scene containing two groups of five objects each, in which the two groups are moving independently of each other, but the objects within each group are moving together as a whole (like a school of fish or a swarm of bees). In this situation, the collective interpretation becomes salient, and the display is seen (at least by adults) as two non-object individuals, not as ten independent objects (Bloom, 2000; Bloom & Veres, 1999). Here we ask if, under the right conditions, 5-month-old infants can construe groups of entities as collective individuals, and enumerate these individuals.

2. The experiment

Our experiment tested whether infants would enumerate moving collections. We employed a habituation methodology.

2.1. Subjects

The participants were 24 normal, full-term infants, with a mean age of 5 months 3 days (range 4 months 25 days to 5 months 18 days). Six additional infants were excluded from the experiment because of failure to complete at least four test trials due to fussiness (two infants) or disinterest (two infants), because of reaching the maximum looking criterion of 30 s on all completed test trials (one infant), or because of an excessive looking preference (as defined by more than 2.5 standard deviations from the group mean) for one of the two kinds of test trials (one infant).

2.2. Procedures and stimuli

Infants were randomly divided into two groups. Half the infants were habituated to two moving collections each composed of three objects presented on a computer screen; half the infants were habituated to four moving collections each composed of three objects. The objects were red, filled-in circles 1.3 cm in diameter (about the size of a dime); previous studies have found that infants can individuate, track, and reason about individual 3-D objects of this size (Chiang & Wynn, 2000; Wynn & Chiang, 1998). Following habituation, all infants were presented with two kinds of test trials: trials depicting two collections of four objects each, and trials depicting four collections of two objects each (see Fig. 1). Thus, all test trials contained the same total number of individual objects (eight), differing only in how these were organized into moving collections. Test displays were therefore equated for contour length (the sum of the perimeters of the individual circles in the set), surface area occupied by the circles, level of contrast in the display, and item density.

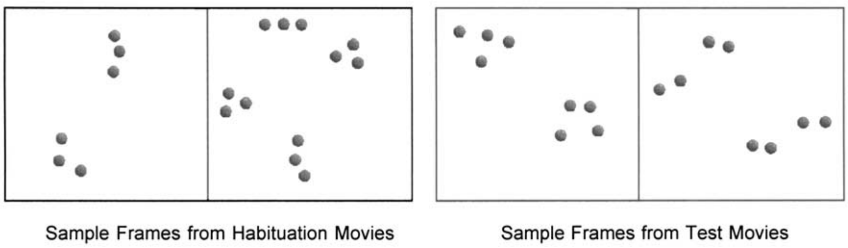

Fig. 1. Sample frames from each of the habituation and test movies.

In both habituation and test displays, items within a collection underwent independent motion with respect to each other, so that the overall configuration and contour of the collection changed continually. The distance between two objects *within* a collection (that is, the distance between any two circles without a third circle between them) ranged from 0 cm (occasional tangential contact of circles) to 3.9 cm. The distance between the closest two objects from *distinct* collections ranged from 0 cm (tangential contact) to 18.3 cm. Thus, the distance between objects from distinct collections was at times equal to or less than the distance between objects within the same collection. Each collection continuously traced a linear path across the computer screen, vertically in habituation trials, horizontally in test trials (see Fig. 2). Stimuli were created with Infini-D software and presented on a Power Macintosh computer with a 21 inch color monitor. Infants sat approximately 80 cm from the screen in an infant seat.

During the habituation phase of the experiment, a trial ended when infants either (a) looked away for 2 consecutive seconds after having looked at the display for at least 1 second, or (b) looked for 30 cumulative seconds, whichever came first. The habituation phase ended and the test phase began when either (a) an infant's total looking time summed across three consecutive trials was less than or equal to half of his or her total looking on the first three habituation trials, or (b) the infant had completed 14 habituation trials, whichever came first. Infants received three pairs of test trials, for a total of six test trials alternately containing two collections of four objects each, and four collections of two objects each, in counterbalanced order; infants completing fewer than two pairs of test trials were excluded from the experiment.

2.3. Results

We predicted that those infants habituated to two collections would look longer at four collections during test, while those habituated to four collections would look longer at two collections during test. Analyses of infants' looking times revealed just this pattern of preferences. A 2 (sex) × 2 (order) × 2 (Habituation condition: two groups of three objects vs. four groups of three objects) ANOVA on infants' mean looking times to the two kinds of test displays yielded a significant Habituation × Test Trial interaction ($F(1, 16) = 12.44$, $P < 0.005$), with infants preferring test displays containing the new number of groups over those containing the habituated number. There were no other significant effects or interactions. Post-hoc tests showed that infants habituated to two groups looked significantly longer on four-group test trials (12.7 s) than two-group test trials (9.7 s) ($t(11) = 2.010$, $P < 0.05$, one-tailed) and that infants habituated to four groups looked marginally longer on two-group test trials (13.3 s) than four-group test trials (11.6 s) ($t(11) = 1.597$, $P = 0.069$) (see Fig. 3). A non-parametric Mann–Whitney U-test confirmed that infants in the two habituation conditions showed significantly different preference patterns ($U = 35.5$, $P < 0.05$, two-tailed).

2.4. Discussion

These results support the existence of number-specific discrimination capacities in infants. Because the total area, summed lengths of the perceptual contours of the items, visual contrast, and item density were identical across our two test displays, infants'

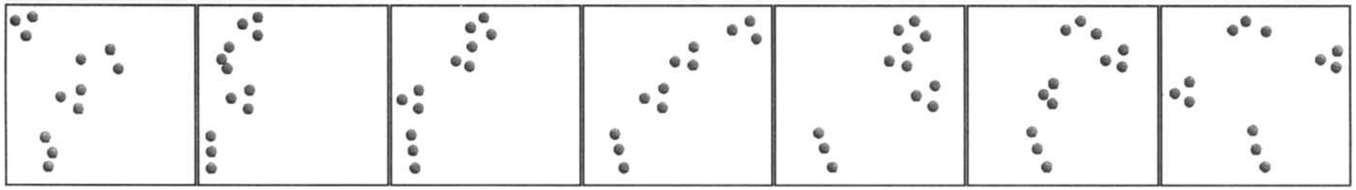

Fig. 2. Sample frames in sequence from the four-groups habituation movie; these frames are separated by approximately 1/2 second (eight frames between each picture; 15 frames per second).

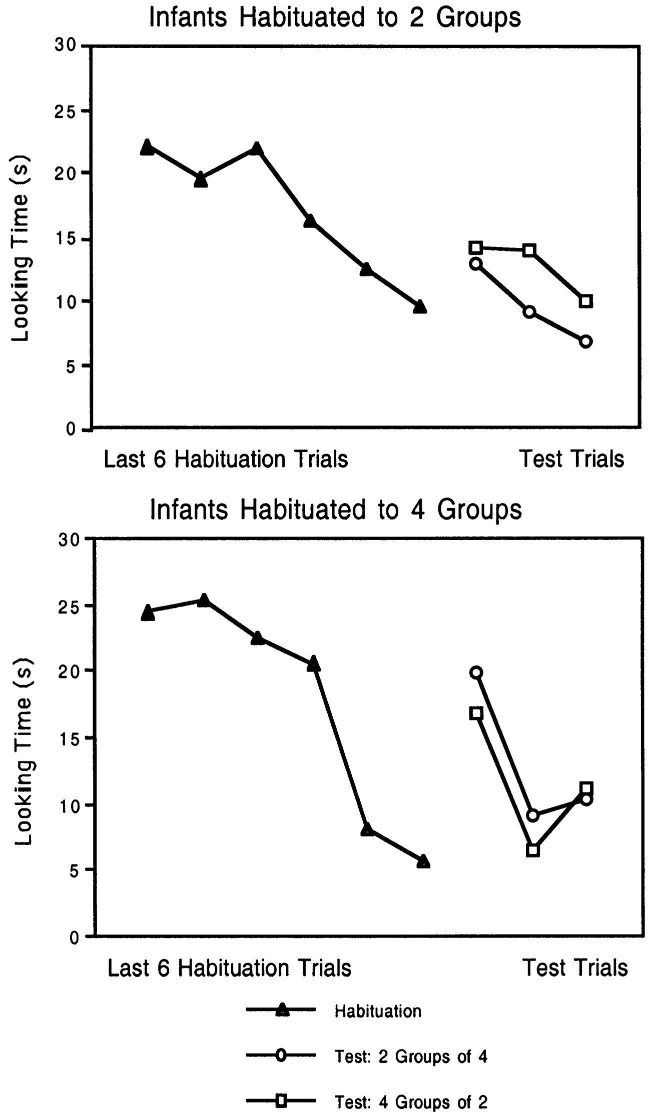

Fig. 3. Looking times on the last six habituation trials and on the three pairs of test trials for infants in the two Habituation conditions.

responses could not have been based on any of these perceptual attributes, but rather must have been based specifically on the *number* of collections in the displays. Our results also support the proposal that infants' enumerative capacities are not restricted to objects; infants can individuate collective entities and treat a collection as an individual for enumeration purposes.

An alternative explanation is that, although the infants were in fact enumerating collections of objects, they nonetheless construed each of the collections as a single distinct object, perhaps viewing the visible red filled-in circles as object *parts* and assuming that the rest of the whole object was invisible or somehow occluded.[1] There are three reasons, however, why this is implausible. First, the circles within a group underwent independent motion with respect to each other, and independent motion of two portions of a visual scene is a primary cue, for infants, that those portions belong to distinct objects (e.g. Spelke, 1988, 1994; cf. Pinto & Bertenthal, 1993). Second, as noted above, the circles were similar in size to objects that infants have been found to successfully track and reason about as distinct individual entities (Chiang & Wynn, 2000; Wynn & Chiang, 1998). Finally, the overall configuration and outer boundaries of each of our collections varied continuously as they moved through space. If infants were construing the collections as objects, they must therefore have been construing them as objects with non-rigid boundaries, akin to plastic bags partially filled with liquid. But even 8-month-old infants have great difficulty tracking and enumerating such non-canonical objects (Huntley-Fenner, Carey, & Solimando, in press), so it is unlikely that our 5-month-old infants were doing so. All these reasons support the conclusion that infants were perceiving our groups of circles as collective, non-object entities.

Infants' successful enumeration of these entities supports the theory that infants are capable of genuine numerical representation. The results reported here also favor a certain perspective on infant cognition more generally. Infants are not limited to making discriminations on the basis of continuous visual properties, nor are they limited to tracking and enumerating individual objects. The scope of their mental life is considerably broader. Our findings, taken together with the findings that infants can enumerate individuals such as actions and sounds, suggest that infants possess a surprisingly rich ontology of individuals that they can discriminate and enumerate.

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References

Antell, S., & Keating, D. P. (1983). Perception of numerical invariance in neonates. *Child Development*, *54*, 695–701.

Bloom, P. (2000). *How children learn the meanings of words* Cambridge, MA: MIT Press.

Bloom, P., & Kelemen, D. (1995). Syntactic cues in the acquisition of collective nouns. *Cognition*, *56*, 1–30.

Bloom, P., & Veres, C. (1999). The perceived intentionality of groups. *Cognition*, *71*, B1–B9.

Callanan, M. A., & Markman, E. M. (1982). Principles of organization in young children's natural language hierarchies. *Child Development*, *53*, 1093–1101.

Chiang, W. -C., & Wynn, K. (2000). Infants' representation and tracking of multiple objects. *Cognition*, *77*, 169–195.

[1] Note that on this interpretation, while the summed length of visible contours, area, and visual contrast would still be equated for the two kinds of test trials, the density of the so-defined items would not be.

Clearfield, M., & Mix, K. (1999). Number versus contour length in infants' discrimination of small visual sets. *Psychological Science*, *10*, 408–411.

Feigenson, L., Carey, S., & Spelke, E. (2002). Infants' discrimination of number vs. continuous extent. *Cognitive Psychology*, *44*, 33–66.

Gallistel, C. R., & Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition*, *44*, 43–74.

Huntley-Fenner, G., Carey, S., & Solimando, A. (in press). Objects are individuals but stuff doesn't count: perceived rigidity and cohesiveness influence infants' representations of small groups of discrete entities. *Cognition*.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). Reviewing object files. *Cognitive Psychology*, *24*, 175–219.

Koechlin, E., Dehaene, S., & Mehler, J. (1997). Numerical transformations in five-month-old human infants. *Mathematical Cognition*, *3*, 89–104.

Leslie, A. M., Xu, F., Tremoulet, P. D., & Scholl, B. J. (1998). Indexing and the object concept: developing "what" and "where" systems. *Trends in Cognitive Science*, *2*, 10–18.

Lipton, J., & Spelke, E. S. (2001, April). *Large number discrimination in 6-month-olds*. Poster presented at the biennial meeting of the Society for Research in Child Development, Minneapolis, MN.

Markman, E. M., Horton, M. S., & McLanahan, A. G. (1980). Classes and collections: principle of organization in the learning of hierarchical relations. *Cognition*, *8*, 227–241.

Mix, K. S., Huttenlocher, J., & Levine, S. C. (1997). Numerical abstraction in infants: another look. *Developmental Psychology*, *33*, 423–428.

Moore, D., Benenson, J., Reznick, J. S., Peterson, P., & Kagan, J. (1987). Effect of auditory numerical information on infants' looking behavior: contradictory evidence. *Developmental Psychology*, *23*, 665–670.

Pinto, J., & Bertenthal, B. I. (1993). Infants' perception of unity in point-light displays of human gait. *Investigative Ophthalmology & Visual Science*, *34*, 1084–1084.

Sharon, T., & Wynn, K. (1998). Infants' individuation of actions from continuous motion. *Psychological Science*, *9*, 357–362.

Simon, T. J. (1997). Reconceptualizing the origins of numerical knowledge: a "non-numerical" account. *Cognitive Development*, *12*, 349–372.

Simon, T. J., Hespos, S. J., & Rochat, P. (1995). Do infants understand simple arithmetic? A replication of Wynn (1992). *Cognitive Development*, *10*, 253–269.

Spelke, E. S. (1988). Where perceiving ends and thinking begins: the apprehension of objects in infancy. In A. Yonas (Ed.), *Perceptual development in infancy. Minnesota symposium on child psychology* (pp. 197–234). Vol. 20. Hillsdale, NJ: Erlbaum.

Spelke, E. S. (1994). Initial knowledge: six suggestions. *Cognition*, *50*, 443–447.

Starkey, P., & Cooper Jr., R. G. (1980). Perception of numbers by human infants. *Science*, *210*, 1033–1035.

Starkey, P., Spelke, E. S., & Gelman, R. (1983). Detection of intermodal numerical correspondence by human infants. *Science*, *222*, 179–181.

Starkey, P., Spelke, E. S., & Gelman, R. (1990). Numerical abstraction by human infants. *Cognition*, *36*, 97–127.

Strauss, M. S., & Curtis, L. E. (1981). Infant perception of numerosity. *Child Development*, *52*, 1146–1152.

Uller, C., Carey, S., Huntley-Fenner, G., & Klatt, L. (1999). The representations underlying infant addition. *Cognitive Development*, *14*, 1–36.

van Loosbroek, E., & Smitsman, A. W. (1992). Visual perception of numerosity in infancy. *Developmental Psychology*, *26*, 916–922.

Wynn, K. (1992a). Addition and subtraction by human infants. *Nature*, *358*, 749–750.

Wynn, K. (1992b). Evidence against empiricist accounts of the origins of numerical knowledge. *Mind & Language*, *7*, 315–332.

Wynn, K. (1995). Origins of numerical knowledge. *Mathematical Cognition*, *1*, 35–60.

Wynn, K. (1996). Infants' individuation and enumeration of actions. *Psychological Science*, *7*, 164–169.

Wynn, K. (1998). Psychological foundations of number: numerical competence in human infants. *Trends in Cognitive Science*, *2*, 296–303.

Wynn, K., & Chiang, W. -C. (1998). Limits to infants' knowledge of objects: the case of magical appearance. *Psychological Science*, *9*, 448–455.