Research Article

INFANTS' INDIVIDUATION AND ENUMERATION OF ACTIONS

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Abstract—*Two experiments examined 6-month-old infants' ability to individuate and enumerate physical actions—the sequential jumps of a puppet. In both experiments, which employed a habituation paradigm, infants successfully discriminated two-jump from three-jump sequences. The sequences of activity in the two experiments provided for an initial exploration of the cues infants use to individuate actions. Results show that (a) infants can individuate and enumerate actions in a sequence, indicating that their enumeration mechanism is quite general in the kinds of entities over which it will operate, (b) actions whose temporal boundaries are characterized by a contrast between motion and absence of motion are especially easy to individuate and enumerate, but nonetheless (c) infants can individuate and enumerate actions embedded in a sequence of continuous motion, indicating that infants possess procedures for parsing an ongoing motionful scene into distinct portions of activity.*

Numerous studies have shown that infants under 1 year of age can enumerate small sets of a range of different kinds of items. Infants discriminate two dots arranged linearly from three (Antell & Keating, 1983; Starkey & Cooper, 1980); they also discriminate two from three, and sometimes three from four, household objects varying in size and arranged randomly in photographs (Starkey, Spelke, & Gelman, 1990; Strauss & Curtis, 1981). Infants presented with computer-generated displays of random checkerboard patterns in independent motion also discriminate two such entities from three and three from four (van Loosbroek & Smitsman, 1990).

Adults, too, are able to enumerate small numbers of objects (up to three to six) without consciously counting them (e.g., Chi & Klahr, 1975; Mandler & Shebo, 1982; Trick & Pylyshyn, 1994). The upper limit of number discrimination is similar in adults and infants, suggesting that the same process is involved in both cases. There are several proposals as to the nature of this *subitization* ability. It has been suggested that it is (a) a process that holistically identifies canonical perceptual patterns that happen to correlate with displays of certain numerosities (Mandler & Shebo, 1982), (b) a component of the visual system, namely, a preattentive individuation and tracking of visual elements in an array (Dehaene & Cohen, 1994; Trick & Pylyshyn, 1994), and (c) a serial counting process that determines number of entities per se (Gallistel, 1990; Wynn, 1992a, 1992b, 1995).

The nature of the entities infants can enumerate is relevant to this issue. If infants' numerical discrimination ability results from a pattern-recognition process, it should not apply to kinds of entities other than objects or depictions of objects. Moreover, even if infants can discriminate number per se (as opposed to perceptual patterns), there are different possibilities as to the nature of the underlying mechanism. It may be restricted to enumerating certain kinds of entities in certain situations; for example, infants might possess a mechanism specifically designed for determining numbers of physical objects in a given location at a given time. Alternatively, the underlying mechanism may be inherently unrestricted in the kinds of entities it can count, in accordance with the *abstraction principle* of counting: All entities, regardless of their kind, can be counted (Gelman & Gallistel, 1978).

Infants' ability to enumerate material objects and depictions of material objects is well documented. In addition, some studies have shown that infants can enumerate punctate sounds in a sequence; when habituated to photographs of either two or three objects, infants looked longer at a disk when it emitted a number of drumbeats that matched the habituated number than when the disk emitted another number of drumbeats (Starkey et al., 1990; see also Moore, Benenson, Reznick, Peterson, & Kagan, 1987). These studies provide initial evidence against perceptual accounts of infants' enumeration abilities.

The present experiments examine infants' ability to enumerate an ontologically different kind of entity: physical actions. A sequence of actions differs from a display of objects in numerous respects. Objects have an enduring existence, but are located at distinct points in space. Actions in a sequence, in contrast, endure only temporarily, occur at distinct points in time, and may or may not occur at precisely the same location in space. Furthermore, with a display of objects, a person has perceptual access to the entire display at once, but with a collection of sequential actions, a person has perceptual access to at most one element at a time and so cannot anticipate the final element. A sequence of actions also differs from a sequence of punctate sounds. A specific material object or agent must be associated with an action, whereas a sound is a disembodied entity—though a sound may emanate from a specific physical object, it is perceived independently of the object in a way that an action cannot be. Furthermore, a sound such as a drumbeat is a punctate event existing at a single instant in time; it has no internal structure or complexity. An action, however, may consist of a structured series of motions over time. Thus, spatial and motion information must be integrated over time to specify an action, making the identification of an action a more complex task than the individuation of a sound. An ability by infants to enumerate physical actions would indicate that the enumeration mechanism accepts a wide variety of entities as input and suggest that infants' ability to detect number does not reduce to a sensitivity to perceptual patterns or a preattentive tracking of visual objects.

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Examining infants' enumeration of actions addresses an additional issue Enumerating a collection of entities requires first individuating them The procedures by which infants parse the visible surface layout into distinct physical objects have been the focus of considerable study (e g , Spelke, 1988), as have been the procedures by which adults analyze the complex and continuous auditory scene into distinct sound events (e g , Bregman, 1990) However, virtually nothing is known about how people individuate actions The individuation of actions is likely to be complex because actions are not definable purely in terms of objective properties Frege's (1893/1980) observation that number is not an inherent property of portions of the world applies as much to actions as it does to physical matter Just as a given physical aggregate may be an instance of many different numbers (three forks is also an instance of 12 tines 2 decks is an instance of 104 cards), so may a given portion of activity (one dance may equally be an instance of 437 steps, one speech may be an instance of 72 utterances) There is no objective fact of the matter as to where, in the continuously evolving scene, one "action" ends and the next "action" begins The individuation of discrete actions from this continuous scene is a cognitive imposition

Thus, the individuation of actions is likely to be a complex cognitive process, yet it is one that is fundamental to thought and language To conceive of events or actions, to talk about them, and to be able to learn words for them entails an ability to parse the continuously evolving scene into discrete segments It has been shown that children as young as 2½ years of age are able to count physical actions (Wynn, 1990), and that children as young as 15 months can segment a complex scene of motion into distinct component actions when assigning a candidate meaning to a novel verb (e g , Gleitman, 1990, Naigles, 1990) However, no studies have investigated the processes by which actions are individuated, or when these processes emerge In the experiments reported here, I undertook such an investigation

EXPERIMENT 1

Method

Subjects

Subjects were 18 healthy, full-term infants 6 months of age (mean age = 6 months 1 day, range 5 months 13 days–6 months 18 days) Twelve were female Six additional infants were excluded from the experiment for failure to complete at least four test trials (4 because of fussiness, 2 because of supreme disinterest)

Design

Half the infants were habituated to a puppet jumping two times, and half to the puppet jumping three times, the ratios of males to females in the two groups were approximately equal Following habituation, the infants were presented with six test trials in which the puppet alternately jumped two and three times Order of test-trial kind (old number first or novel number first) was counterbalanced Infants completing fewer than four test trials were excluded from the experiment Half the infants within each habituation and ordering group received test trials matched for tempo and the other half received test trials matched for overall duration, as described later in this section

Apparatus

Infants sat in an infant seat facing a display stage that could be hidden by the lowering of a curtain Additional curtains surrounded the display, blocking the rest of the room from view A puppet could be placed in the center of the stage, a wooden dowel (not visible to the infants) protruded from the back of the puppet and poked through the back wall of the stage to serve as a lever by which a hidden experimenter manipulated the puppet (see Fig 1) Two hidden observers monitored infants' looking times by means of button-boxes attached to a computer The observers could not see the display and were unaware of the number of jumps on each trial Parents and a background observer stood behind the infant, out of his or her range of vision Throughout the experiment, soft classical piano music played in the background

Procedure

Prior to the experiment, the infants were shown the puppet and allowed to hold it Upon being placed in the infant seat, they received a brief introduction to the empty display A gloved hand patted the floor and walls of the display, and the curtain was raised and lowered

On habituation trials, the curtain was raised to reveal the stationary puppet Approximately 1 s later, the experimenter executed the specified jump sequence, measuring tempo and duration of jumps with a metronome Upon completion of the jump sequence (½ s after the descent of the final jump), timing of the infant's looking to the now-stationary puppet commenced Jumps were soundless At the end of the trial, the curtain dropped to obscure the display briefly (1 5 s) then rose

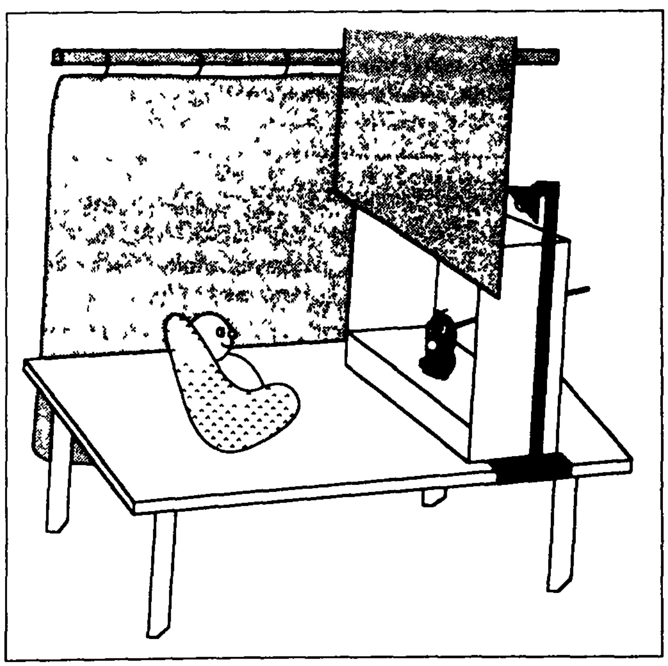


Fig 1 Diagram of the testing situation and apparatus

to initiate the next trial. A trial ended when (a) after 2 or more seconds of continuous looking, the infant looked away for at least 2 continuous seconds or (b) the infant looked for 30 s cumulative. Habituation was reached when (a) looking time on 3 consecutive trials excluding the first 3 was less than half of the infant's looking time on the first 3 trials or (b) the infant completed 14 trials without meeting Criterion (a). Upon habituation, the infant received a 40-s break, during which he or she was turned away from the display and allowed to interact with a parent.

Test trials followed the same procedure as habituation trials. Each infant contributed an equal number of old- and novel-number test trials (e.g., if an infant completed five trials, only the first four were included).

Structure of jump sequences

Jumps were of 1 s duration (½-s ascent, ½-s descent), with a pause between jumps. To control for the possibility that infants might be sensitive to tempo or overall duration of jump sequences rather than number of jumps, the old-number test jump sequence was always different from the habituation sequence in both tempo and total duration. The novel-number test jump sequence was always the same as the habituation sequence on one of these dimensions. For half the infants, it had the same overall duration, and for half it had the same tempo. Thus, in terms of duration and tempo, the most novel test sequence was that with the habituated number of jumps (see Table 1).

Results and Discussion

A 2 (habituation condition: two or three jumps) × 2 (control condition: test trials matched for duration or tempo) × 2 (sex) × 2 (trial kind: old or novel number of jumps) repeated measures analysis of variance on infants' mean looking times revealed a significant effect of trial kind, with a mean looking time of 6.7 s on novel-number trials and 4.3 s on old-number trials, $F(1, 10) = 16.970, p < .005$. The only other significant effect was a Trial Kind × Sex × Habituation Condition interaction, with male infants habituated to two jumps showing a stronger tendency to look at the new over the habituated number of jumps than males habituated to three jumps and the reverse pattern for females (though all four groups looked longer on the novel-number trials), $F(1, 10) = 6.778, p < .05$. A similar analysis on infants' proportionate, rather than raw, looking times[1] also obtained a significant effect of trial kind, with a mean proportion of .59 of infants' total looking time occurring on novel-number trials and .41 on old-number trials, $F(1, 10) = 14.139, p < .005$. There were no other significant effects or interactions. Figure 2 shows the infants' mean looking times over the three pairs of test trials.

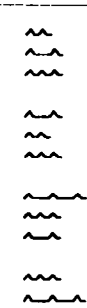
Thus, the infants distinguished between the old-number jump sequences and the novel-number ones. This result indicates that the infants were (a) individuating the jumps in the sequences and (b) enumerating them.

How were the infants individuating the jumps? An examination of individuation processes in other domains may be relevant. Surfaces in the visual layout that are clearly spatially separated are construed by infants as corresponding to distinct objects (Spelke, 1988), and portions of the auditory scene that are temporally separated by intervals of silence are construed as distinct acoustic events (Bregman, 1990). A similar principle may apply in the individuation of actions. In this experiment, each jump was bounded on both sides by a motionless pause on the part of the puppet; thus, the jump sequences were composed of separated portions of motion placed against a motionless backdrop. The boundaries specified by these disconti-

1. Proportionate looking time on old-number trials = $TLO/(TLO + TLN)$ and proportionate looking time on novel-number trials = $TLN/(TLO + TLN)$, where TLO = total looking time summed across old-number test trials and TLN = total looking time summed across novel-number test trials.

Table 1 *Structure of jump sequences in Experiment 1*

Habituation group	Jump sequences controlled for	Trial kind	Tempo (length of interjump interval in seconds)	Overall duration of jump sequence (in seconds)	Schematic depiction
2 jumps	Duration	Habituation (2 jumps)	1/2	3	
		Test (2 jumps)	2	4.5	
		Test (3 jumps)	1/2	4.5	
2 jumps	Tempo	Habituation (2 jumps)	2	4.5	
		Test (2 jumps)	1/2	3	
		Test (3 jumps)	1/2	4.5	
3 jumps	Duration	Habituation (3 jumps)	2	7.5	
		Test (3 jumps)	1/2	4.5	
		Test (2 jumps)	2	4.5	
3 jumps	Tempo	Habituation (3 jumps)	1/2	4.5	
		Test (3 jumps)	2	7.5	
		Test (2 jumps)	2	4.5	



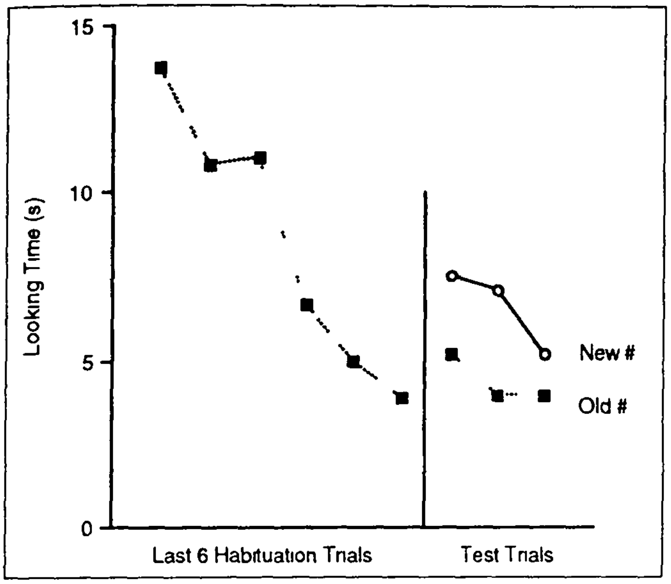


Fig 2 Mean looking time to the stationary puppet following the novel number of jumps versus the old number of jumps in Experiment 1 (motionless pause between jumps)

nuities in motion may have provided a powerful cue for the individuation of actions in each sequence

However the specification of item boundaries by spatial or temporal separation from other portions of the scene is not always necessary for individuation For instance two objects are perceived as distinct individuals when they move with respect to each other, even if they remain in continuous contact, as, for example, when a ball rolls on a table (e g , Spelke 1988) Similarly, a continuous portion of sound can be perceived as a number of distinct auditory entities as occurs both in speech perception and in more primitive auditory analyses (e g , Bregman, 1990) These facts suggest the possibility that the temporal bounding of individual portions of action by a contrast between motion and absence of motion is a useful but not essential, cue for determining distinct actions in a scene For adults at least distinct actions need not be bounded by motionlessness, a horse in a steeplechase race need not halt between jumps To examine whether the same holds true in infants' individuation of actions, a second experiment was conducted

EXPERIMENT 2

As in the first experiment, one group of infants was habituated to two jumps, another to three jumps, in the test phase, the infants were presented alternately with two- and three-jump sequences In this experiment, however, the puppet was in constant motion throughout the jump sequence, its head wagged from side to side in an exaggerated fashion between jumps, and also briefly following the final jump of the sequence Thus, a segmentation on the basis of motion versus no motion would not suffice to parse the sequence of activity into discrete segments

Method

Subjects

Twenty-two 6-month-olds participated (mean age = 6 months 5 days, range 5 months 22 days–6 months 22 days) Ten were female Eleven additional infants were excluded for the following reasons fussiness (n = 5), lack of interest (n = 4), falling asleep (n = 1), and experimenter error (n = 1) The design apparatus and procedure were the same as in Experiment 1

Structure of jump sequences

On each trial, the curtain was raised upon a stationary puppet The first jump initiated the sequence, between jumps, the puppet s head wagged from side to side continuously in an exaggerated fashion Following the final jump in the sequence, the puppet wagged its head for an additional ½ s, and then the timing of the infant's looking commenced immediately For half the infants in each habituation and ordering group, test sequences were matched for tempo, with the overall duration of the old- and novel-number sequences differing equally (one longer, one shorter) from that of the habituated sequence For the remaining infants in each group, test sequences were matched for overall duration, with the tempo of the old- and novel-number sequences differing equally (one faster, one slower) from that of the habituated sequence Thus, neither the old- nor the novel-number test sequences matched the habituated sequence on either dimension (see Table 2)

Results and Discussion

A 2 (habituation condition two or three jumps) × 2 (control condition test trials matched for duration or tempo) × 2 (sex) × 2 (trial kind old or novel number of jumps) repeated measures analysis of variance conducted on infants' mean looking times revealed a significant effect of trial kind, with a mean looking time of 6 0 s on novel-number trials and 5 2 s on old-number trials $F(1\ 14) = 4\ 490, p = \ 05$ A similar analysis on infants' proportionate, rather than raw, looking times also obtained a significant effect of trial kind, with a mean proportion of 54 of infants' total looking time occurring on novel-number trials and 46 on old-number trials, $F(1, 14) = 5\ 153, p < \ 05$ No other effects or interactions were significant Figure 3 shows the infants mean looking times over the three pairs of test trials

These results show that bounding individual actions on both sides with intervals of motionlessness is not required for individuating those actions However, although not necessary, it may nonetheless be a useful cue To address this question, the infants' performance in the two experiments was compared to see if discrimination between novel- and old-number sequences was stronger in Experiment 1 than in Experiment 2 A 2 (Experiment 1 or 2) × 2 (habituation condition two or three jumps) × 2 (sex) × 2 (trial kind old or novel number of jumps) analysis of variance on infants' mean looking times revealed a significant interaction between trial kind and experiment Infants in Experiment 1 distinguished between old-number and novel-

Table 2 *Structure of jump sequences ın Experıment 2*

Habıtuatıon group	Jump sequences controlled for	Trıal kınd	Tempo (length of ınterjump ınterval ın seconds)	Overall duratıon of jump sequence (ın seconds)	Schematıc depıctıon
2 jumps	Duratıon	Habıtuatıon (2 jumps)	2	4 5	^ ^
		Test (2 jumps)	3	5 5	^ ^
		Test (3 jumps)	1	5 5	^^^
2 jumps	Tempo	Habıtuatıon (2 jumps)	2	4 5	^ ^
		Test (2 jumps)	1	3 5	^^
		Test (3 jumps)	1	5 5	^^^
3 jumps	Duratıon	Habıtuatıon (3 jumps)	2	7 5	^ ^ ^
		Test (3 jumps)	1	5 5	^^^
		Test (2 jumps)	3	5 5	^ ^
3 jumps	Tempo	Habıtuatıon (3 jumps)	1/2	4 5	^^^
		Test (3 jumps)	1	5 5	^^^
		Test (2 jumps)	1	3 5	^^

number sequences more strongly than dıd ınfants ın Experıment 2, $F(1, 32) = 9\ 380$, $p < 005$ A sımılar analysıs on the ınfants' proportıonate, rather than raw, lookıng tımes also obtaıned a sıgnıficant Trıal Kınd × Experıment ınteractıon, $F(1, 32) = 4\ 869$, $p < 05$ [2]

There are varıous ways the ınfants may have ındıvıduated actıons ın Experıment 2, each entaılıng dıfferent parsıng procedures One possıbılıty ıs that the ınfants selected the ındıvıdual jumps out from the backdrop of head-waggıng actıvıty and enumerated them There are two ways ın whıch the ınfants mıght have done thıs They mıght have dıstınguıshed the jumpıng motıon as qualıtatıvely dıfferent from the head waggıng, whıch mıght have resulted ın theır enumeratıng the jumps ıf for example, the jumpıng ıs a more salıent kınd of motıon than the head waggıng In thıs case, the ınfants would have been usıng the transıtıon from one kınd of motıon to another (the jumpıng-waggıng contrast) to specıfy the temporal boundarıes of each actıon Alternatıvely, ıf ınfants possess a concept of "jump," they may have ıdentıfied the puppet's jumps as ınstances of the concept—that ıs, used theır concept to ıdentıfy the boundarıes of each actıon, wıthout reference to the ınterverııng motıon

A dıfferent possıbılıty ıs that the ınfants ındıvıduated and enumerated not the jumps alone, but the repeatıng jumpıng-followed-by-head-waggıng pattern of motıon ın the sequences To count the number of repetıtıons of thıs composıte motıon pattern would entaıl a specıficatıon of more abstractly defined boundarıes—those ımposed by the repeatıng nature of the pattern ıtself The exıstence of these dıstınct possıbılıtıes hıghlıghts a fundamental property of actıons They requıre a cognıtıve ınterpretatıon ın theır ındıvıduatıon

2 Both analyses also revealed a sıgnıficant maın effect of trıal kınd wıth ınfants showıng a preference for the novel-number trıals for mean raw lookıng tıme, $F(1, 32) = 30\ 143$, $p < 0001$ for mean proportıonate lookıng tıme, $F(1, 32) = 25\ 111$, $p < 0001$ The analyses also revealed a sıgnıficant Trıal Kınd × Sex × Habıtuatıon Condıtıon ınteractıon wıth males habıtuated to two jumps showıng a stronger preference for the novel-number sequences than males habıtuated to three jumps, and the reverse pattern for females (though all four groups showed a preference for the novel-number sequences) for mean raw lookıng tıme, $F(1, 32) = 4\ 158$, $p < 005$, for mean proportıonate lookıng tıme, $F(1, 32) = 6\ 693$, $p < 05$ Fınally, the analysıs on mean raw lookıng tıme obtaıned a sıgnıficant maın effect of habıtuatıon condıtıon, wıth ınfants habıtuated to two jumps gıvıng longer looks on average than ınfants habıtuated to three jumps, $F(1, 32) = 6\ 498$, $p < 05$

GENERAL DISCUSSION

The results ındıcate that ınfants can ındıvıduate and enumerate physıcal actıons ın a sequence Actıons whose temporal boundarıes are characterızed by a contrast between motıon and absence of motıon are especıally easy to ındıvıduate and enumerate, but nonetheless ınfants can ındıvıduate and enumerate

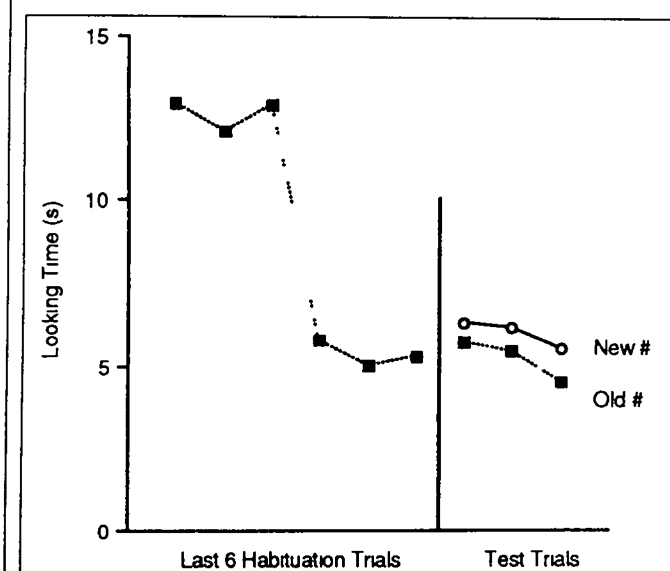


Fıg 3 Mean lookıng tıme to the statıonary puppet followıng the novel number of jumps versus the old number of jumps ın Experıment 2 (puppet ın constant motıon between jumps)

actions embedded in a sequence of continuous motion, indicating that they possess procedures for parsing an ongoing motionful scene into distinct portions of activity These findings inform our knowledge both of infants' individuation processes and of their enumeration mechanism

The ability to carve up portions of experience into discrete units is a fundamental cognitive achievement Much is known about infants' concept of "individual" as it applies to physical objects, and about adults' individuation of sounds in the auditory stream But there exist processes for individuating other kinds of entities as well Whether the very same principles, at a suitably abstract level of description, are used in the individuation of different ontological kinds of entities (see Bloom, 1994, Bloom & Kelemen, 1995), or whether distinct principles apply to different kinds, requires further experimental investigation

Finally, these experiments provide additional evidence that infants' enumeration mechanism does not operate over low-level perceptual information, because it is highly unlikely that such information exists in common across distinct arrays of actions, sounds, and objects of equivalent number Rather, the enumeration mechanism may take as input conceptually specified entities—entities that the cognitive system conceptualizes as individuals Adults construe many different kinds of entities as individuals and enumerate them In addition to physical objects, actions, and sounds, these entities include socially defined events such as parades and races, politically or culturally defined entities such as countries and religions, and abstract entities such as thoughts and mistakes The results reported here allow the speculation that infants' enumeration mechanism may be equally general

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