Detection of Intermodal Numerical Correspondences by Human Infants

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The rate of recovery of Ca^{2+} concentrations from trough levels is high when compared to the rate observed after decreases induced by excitatory amino acids (*14*). In view of the diffusion speed of Ca^{2+} in the extracellular space (*5*), this recovery rate cannot be explained solely by the migration of Ca^{2+} from zones surrounding the epileptogenic focus. Additional mechanisms must participate in the recovery, perhaps including active Ca^{2+} extrusion from cellular elements (*15*) or transition from bound to free Ca^{2+} in the extracellular matrix.

The humps often observed on the descending limb of Ca^{2+} recordings and the Ca^{2+} increases regularly detected in deep cortical layers during paroxysmal field potentials cannot be explained by a defective subtraction of the field potential from the signal of the ion-sensitive side: at the cortical surface full-sized field potentials were often recorded with no detectable signal on the Ca^{2+} recording. Moreover, in control experiments at various cortical depths in which artificial field potentials were delivered by stimulating electrodes, no appreciable artifact due to a defective subtraction was seen. Increases in extracellular Ca^{2+} have been observed during seizures (*4, 16*), particularly in deep layers (*17*). Several mechanisms may account for such a process, among which a shrinkage of the extracellular space due to osmotic imbalance is the most likely (*17*).

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Detection of Intermodal Numerical Correspondences by Human Infants

Abstract. *Infants prefer to look at an array of objects that corresponds in number to a sequence of sounds. In doing so, infants disregard the modality (visual or auditory) and type (object or event) of items presented. This finding indicates that infants possess a mechanism that enables them to obtain information about number.*

Before children go to school they exhibit knowledge of enumerative procedures such as counting, of numerical relationships such as equivalence, and of arithmetic operations such as addition (*1*). These observations suggest that early mathematical knowledge develops from an innate base. Here we present evidence that 7-month-old infants match the number of objects in a spatial display to the number of sounds in a temporal sequence. These findings indicate that infants can detect numerical information and that they do so by use of a mechanism that is not limited to a single modality of sensation.

Human infants discriminate among visible displays of two, three, or four dots of white light (*2*) and between pictures of two or three objects varying in color, shape, size, texture, and arrangement (*3*). Although suggestive, these experiments do not reveal whether the basis of the discrimination is numerical information as such or specific visual patterns (*4*). We have now addressed this issue by investigating whether infants could detect numerical correspondences between sets of visible items and sets of audible items.

The experiments used a preferential looking procedure adapted from studies

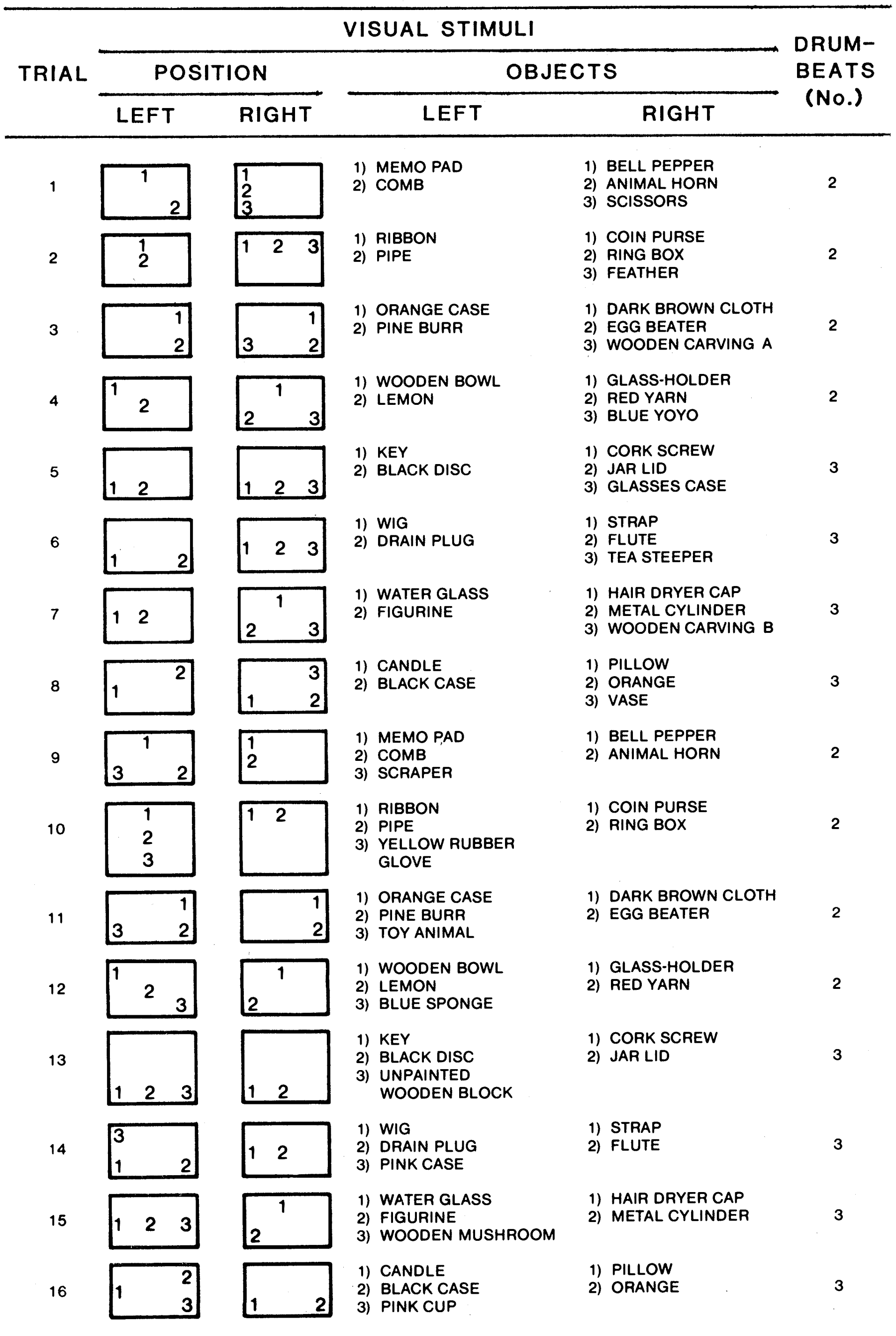
Table 1. Attention to and preferences for numerically corresponding displays.

Experiment	Trial block	Duration of attention (seconds)		Preference for corresponding display		
		Corresponding display	Noncorresponding display	Proportion of duration†	Proportion of subjects‡	Subjects (*N*)
1	1	2.11 ± 0.89	1.99 ± 0.81	0.51	0.44	7
	2	2.02 ± 0.99	1.51 ± 0.79	0.58***	0.75**	12
	1 + 2	2.06 ± 0.71	1.75 ± 0.73	0.55**	0.75**	12
2	1	2.93 ± 1.09	2.91 ± 0.84	0.50	0.50	4
	2	2.74 ± 1.38	1.92 ± 0.91	0.58***	1.00***	8
	1 + 2	2.84 ± 1.23	2.42 ± 0.57	0.54**	0.75	6
3	1	3.03 ± 0.81	2.59 ± 1.02	0.54	0.56	9
	2	2.64 ± 0.95	2.32 ± 1.06	0.54	0.56	9
	1 + 2	2.84 ± 0.77	2.46 ± 0.80	0.54***	0.75*	12
1 + 2 + 3	1	2.64 ± 0.98	2.41 ± 0.96	0.52	0.50	20
	2	2.41 ± 1.09	1.92 ± 0.98	0.57***	0.72***	29
	1 + 2	2.53 ± 0.92	2.17 ± 0.79	0.54***	0.75***	30

†$P_d = D_c/(D_c + D_n)$, where P_d is the mean proportion of duration averaged over trials, and D_c and D_n are the mean durations of attention averaged over the sets of corresponding displays (c) and noncorresponding displays (n). This proportion was compared with that expected by chance, 0.50; significance was assessed by one-tailed *t*-tests with 15 degrees of freedom (d.f.) (experiments 1 and 3), 7 d.f. (experiment 2), or 39 d.f. (overall). ‡$P_s = S_c/(S_c + S_n)$, where P_s is the proportion of subjects, and S_c and S_n are the numbers of subjects whose mean proportion of duration was greater on the corresponding displays (c) or the noncorresponding displays (n); significance was assessed by one-tailed sign tests. $*P < 0.05$. $**P < 0.025$. $***P < 0.01$.

of intermodal perception (*5*). Infants 6 to 8 months old viewed two photographic displays presented side by side. One display contained two objects, the other three. While infants watched these displays, they heard two or three drumbeats from a central location. Their time looking at the displays was subsequently recorded for 10 seconds. Infants attend preferentially to a visible object that corresponds to an accompanying sound (*5*). If they detect the number of items in visible and audible displays, they should look at the display of objects that matches, in number, the sequence of sounds.

Sixteen infants participated in experiment 1. They saw a variety of slide photographs of heterogeneous household items (*6*). Different items, in different arrangements, appeared on each slide (Fig. 1). The auditory accompaniment consisted of two or three beats (1.33 beats per second) from a drum concealed behind the projection screen. On each trial, the slides were displayed during the presentation of the sounds and for 10 seconds thereafter. Then they were removed and a new pair was displayed, thus beginning the next trial. Each infant was presented with at least 16 and no more than 32 trials (*7*). On each trial, the duration of looking at each of the two visible displays was recorded during the 10-second period that followed the offset of the sound. The recordings were made by two observers who could not see the displayed slides (*8*).



TRIAL	VISUAL STIMULI				DRUMBEATS (No.)
	POSITION		OBJECTS		
	LEFT	RIGHT	LEFT	RIGHT	
1	1 2	1 2 3	1) MEMO PAD 2) COMB	1) BELL PEPPER 2) ANIMAL HORN 3) SCISSORS	2
2	1 2	1 2 3	1) RIBBON 2) PIPE	1) COIN PURSE 2) RING BOX 3) FEATHER	2
3	1 2	1 3 2	1) ORANGE CASE 2) PINE BURR	1) DARK BROWN CLOTH 2) EGG BEATER 3) WOODEN CARVING A	2
4	1 2	1 2 3	1) WOODEN BOWL 2) LEMON	1) GLASS-HOLDER 2) RED YARN 3) BLUE YOYO	2
5	1 2	1 2 3	1) KEY 2) BLACK DISC	1) CORK SCREW 2) JAR LID 3) GLASSES CASE	3
6	1 2	1 2 3	1) WIG 2) DRAIN PLUG	1) STRAP 2) FLUTE 3) TEA STEEPER	3
7	1 2	1 2 3	1) WATER GLASS 2) FIGURINE	1) HAIR DRYER CAP 2) METAL CYLINDER 3) WOODEN CARVING B	3
8	2 1	3 1 2	1) CANDLE 2) BLACK CASE	1) PILLOW 2) ORANGE 3) VASE	3
9	1 3 2	1 2	1) MEMO PAD 2) COMB 3) SCRAPER	1) BELL PEPPER 2) ANIMAL HORN	2
10	1 2 3	1 2	1) RIBBON 2) PIPE 3) YELLOW RUBBER GLOVE	1) COIN PURSE 2) RING BOX	2
11	1 3 2	1 2	1) ORANGE CASE 2) PINE BURR 3) TOY ANIMAL	1) DARK BROWN CLOTH 2) EGG BEATER	2
12	1 2 3	1 2	1) WOODEN BOWL 2) LEMON 3) BLUE SPONGE	1) GLASS-HOLDER 2) RED YARN	2
13	1 2 3	1 2	1) KEY 2) BLACK DISC 3) UNPAINTED WOODEN BLOCK	1) CORK SCREW 2) JAR LID	3
14	3 1 2	1 2	1) WIG 2) DRAIN PLUG 3) PINK CASE	1) STRAP 2) FLUTE	3
15	1 2 3	1 2	1) WATER GLASS 2) FIGURINE 3) WOODEN MUSHROOM	1) HAIR DRYER CAP 2) METAL CYLINDER	3
16	2 1 3	1 2	1) CANDLE 2) BLACK CASE 3) PINK CUP	1) PILLOW 2) ORANGE	3

Fig. 1. The order of displays given to one infant.

The infants attended longer to the numerically corresponding display than to the noncorresponding display; this preference was largely limited to the second block of trials (Table 1). A majority of the infants preferred the numerically corresponding display (Table 1). In the first block of trials, infants looked longer at the three-object display regardless of the number of drumbeats sounded. These results were obtained again in experiment 2, a replication with eight additional infants (Table 1).

Experiment 3 was an investigation of whether these preferences could have been based on temporal rather than numerical information. Temporal information provided a possible basis for intermodal matching because the three-object display presumably required more scanning time than the two-object display, and the duration of the three-beat sequence was greater than that of the two-beat sequence. In this experiment, the durations of the two- and three-beat sequences were equated. The 16 infants that were observed again attended longer to the numerically corresponding display (Table 1).

When the three experiments are considered together the two-object display was attended to longer when accompanied by two drumbeats than by three and the three-object display was attended to longer when accompanied by three drumbeats than by two (*9*). A majority of infants preferred the numerically corresponding display. An examination of the distribution of attention of each of these infants across all trials of the experimental session revealed that several infants exhibited a pattern characterized by the presence of one or more uninterrupted runs of several trials in which the numerically corresponding display was preferred and several more infants, although they exhibited shorter runs, preferred the corresponding display on a significant number of trials (*10*).

The findings of these experiments shed light on the mechanisms possibly underlying the infants' ability to obtain information about number. Infants detected numerical correspondences across two very different kinds of display. In order to detect these correspondences, they must have disregarded the modality of presentation (visual or auditory) and the type of items presented (objects or events). No visual pattern matching procedure could, by itself, account for the detection of these correspondences. The infant's enumerative procedure must be more general.

It remains to be determined whether infants' numerical categories are as differentiated as those of older children and whether they are absolute (in the sense of "two" and "three") or relative (in the sense of "more numerous" and "less numerous"). It is also not known how the abilities of infants are related developmentally to those of older children. Answers to these questions may begin to elucidate the psychological foundation of number.

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4. For one development of this view, see D. Klahr and J. G. Wallace [*Cognitive Development, An Information Processing View* (Erlbaum, Hillsdale, N.J., 1976)].
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6. Infants were seated either in an infant seat or on the lap of a parent who wore glasses that occluded his or her view of the displays. The slides were rear-projected onto a 64-cm by 89-cm screen located 60 cm from the infant. The projected displays subtended visual angles of 21.8° (vertical) by 25.2° (horizontal) and were separated by 25.2°. The objects in each slide were presented against a white background, each spatially separated from the others. Room lighting was dim.
7. The experiment was terminated if an infant became fretful or drowsy. Eleven infants completed all 32 trials. One infant failed to complete 16 trials and was replaced. The remaining five infants completed from 17 to 29 trials. All infants were presented with 16 unique pairs of visible displays (Fig. 1). The order of presentation and the lateral position of displays within a pair were counterbalanced across infants. Each infant was presented with two drumbeats on half of the trials and with three drumbeats on the other half. For half of the infants, a particular display pair was accompanied by two drumbeats; for the rest, it was accompanied by three beats. The presentations of the materials on the first 16 trials were repeated on the second 16 trials.
8. Interobserver reliability was greater than 0.9. The observers viewed the infants through peepholes located to the left or right of the projection screen. Partitions blocked their view of the screen and hence the displays. Parents' opaque glasses did not reflect light from the displays. Moreover, two experiments revealed that the observers could neither see reflections of the displays on the infants' corneas nor analyze the infants' patterns of eye scanning to determine the number of objects on each side. Use of corneal reflections was tested in experiment 4, in which four infnats were presented with the materials in Fig. 1. Eight observers (two per infant) who had also served as observers in the main experiments monitored corneal reflections from the displays and judged, as best they could, the lateral position of the two-object display. The observers' proportions of correct judgments did not differ from that expected by chance (proportion, 0.49). Use of scanning patterns was tested in experiment 3 by instructing one of the two observers present at each session to use such patterns to judge the position of the two-object display. Again, judgments were at chance level.
9. Across experiments, a preference for the two-object display when accompanied by two drumbeats was present in the first block of trials (proportion of duration, 0.54, $P < 0.05$), in the second block (proportion, 0.55, $P < 0.01$), and across both blocks (proportion, 0.55, $P < 0.01$); a preference for the three-object display when accompanied by three drumbeats was not present in the first block of trials (proportion, 0.51) but was present in the second block (proportion, 0.58, $P < 0.01$) and across both blocks (proportion, 0.54, $P < 0.01$).
10. Of the 30 infants who had an overall preference for the corresponding display, 11 exhibited one or more long uninterrupted runs as identified by a runs test [S. Siegel, *Nonparametric Statistics* (McGraw-Hill, New York, 1956)] for the presence of significantly few runs of trials in which either the corresponding display was preferred or the noncorresponding display was preferred. An additional five infants, who did not exhibit a long run, nevertheless preferred the corresponding display on a significant number of trials as indicated by a sign test.
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A Microtubule Meshwork Associated with Gametic Pronucleus Transfer Across a Cell-Cell Junction

Abstract. *In conjugating* Tetrahymena, *a cellular assembly composed of a microtubule meshwork appears to be required for the transfer of gametic pronuclei across the junction that separates the conjugating cells. This assembly is suggestive of a gametogenic cell division in ancient predecessors of ciliates, with* Tetrahymena *retaining only the associated nuclear division and export.*

Fertilization in the unicellular eukaryote *Tetrahymena thermophila* includes a reciprocal exchange of migratory gametic pronuclei across a temporary junction that separates the two conjugating cells. *Tetrahymena thermophila* is a useful model system for the study of fertilization. Conjugation can be induced efficiently and synchronously in large populations of *T. thermophila*. The nuclear events occurring during conjugation have been observed by light microscopy and are well characterized (*1*). The exchange of gametic pronuclei can be blocked with hyperosmotic shock (*2*) and microtubule assembly inhibitors (*3*). Genetic methods for the detection and selection of fertilization failures in populations of conjugating cells are available (*4*, *5*) and should allow the isolation and characterization of mutants defective in fertilization functions.

The two conjugating cells are separated by a specialized junction (*6*) covering an area close to 100 μm^2. It consists of the plasma membrane of each of the two cells, separated by a very regular gap of around 30 nm and interrupted by channels or pores that provide cytoplasmic connections between the two cells (Fig. 1A). The cytoplasmic side of the membrane is continuously lined with an epiplasmic layer approximately 35 nm thick (*7*).

The nuclear events of conjugation (*1*) begin with meiosis of the diploid (germline) micronucleus. Only one of the four haploid meiotic products remains functional in each cell. A mitotic division of this product generates to gametic pronuclei; one, the migratory pronucleus, lies against the junction that separates the two cells while the other, the stationary pronucleus, lies farther away. Fertilization involves the reciprocal and generally simultaneous exchange of migratory pronuclei across the junction. The incoming migratory pronucleus immediately fuses with the stationary pronucleus of the recipient, thus generating a fertilization nucleus in each conjugant. Within a few minutes after fusion, the fertilization nucleus undergoes the first postzygotic mitotic division.

Our objective was to characterize the ultrastructure of fertilization in *Tetrahymena* in an attempt to understand why inhibitors of microtubule assembly block pronuclear transfer across the junction. Our study revealed a basket-like structure, consisting of a meshwork of microtubules, associated with each migratory pronucleus. This meshwork is similar to one reported in a ciliate distantly related