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RESEARCH ARTICLES

Intersensory Redundancy and 7-Month-Old Infants' Memory for Arbitrary Syllable–Object Relations

Lakshmi J. Gogate
Department of Psychiatry
State University of New York at Brooklyn

Lorraine E. Bahrick
Department of Psychology
Florida International University

Seven-month-old infants require redundant information, such as temporal synchrony, to learn arbitrary syllable–object relations (Gogate & Bahrick, 1998). Infants learned the relations between 2 spoken syllables, /a/ and /i/, and 2 moving objects only when temporal synchrony was present during habituation. This article presents 2 experiments to address infants' memory for these relations. In Experiment 1, infants remembered the syllable–object relations after 10 min, only when temporal synchrony between the vocalizations and moving objects was provided during learning. In Experiment 2, 7-month-olds were habituated to the same syllable–object pairs in the presence of temporal synchrony and tested for memory after 4 days. Once again, infants learned and showed emerging memory for the syllable–object relations 4 days after original learning under the temporally synchronous condition. These findings are consistent with the view that prior to symbolic development, infants learn and remember word–object relations by perceiving redundant information in the vocal and gestural communication of adults.

Requests for reprints should be sent to Lakshmi J. Gogate, Department of Psychiatry, State University of New York at Brooklyn, P.O. Box 1203, Brooklyn, NY 11203. E-mail: lgogate@netmail.hscbklyn.edu

Infants remember visual events for a long period of time (see Rovee-Collier, 1984). For example, 3-month-olds remember the motions of objects 12 weeks following familiarization to visual displays (Bahrick & Pickens, 1995). Five-and-a-half-month-olds remember the activities that people perform 7 weeks following familiarization to dynamic video displays (Bahrick, Gogate, & Ruiz, 2000). Studies have also shown that 2-month-olds remember extended speech (nursery rhymes) 3 days following familiarization (Spence, 1996), and 7½-month-olds remember words from a passage they heard 2 weeks earlier (Jusczyk & Hohne, 1997). However, no studies have shown whether preverbal infants remember the relations between what they see and hear, such as novel objects and words. Learning and remembering these relations can facilitate the discovery of word meaning and is a precursor to lexical comprehension. However, the perceptual and memory processes underlying word-to-object mapping during the first year have not been investigated. Because of the paucity of investigations, the domain of early word comprehension has been called the "black hole" of language development (Golinkoff & Hirsh-Pasek, 1998).

How do infants relate words and objects from ongoing communication? Words are arbitrarily related to objects through convention and are learned through sensory experience. For example, an infant can relate the word *ball* with the object, ball, by hearing the word and seeing the object. Some researchers have hypothesized that infants map words onto existing representations of objects (Stemmer, 1989), or associate words and objects (Plunkett, 1997; Smith, 1995; Stager & Werker, 1997; Werker, Cohen, Lloyd, Casasola, & Stager, 1998) or concepts (Jusczyk & Hohne, 1997). It is our view that young infants relate words and objects by detecting intersensory redundancy (Gogate & Bahrick, 1998; Gogate, Walker-Andrews, & Bahrick, 2001; also see Bates, 1993; Sullivan & Horowitz, 1983; Zukow-Goldring, 1997). Infants' perceptual system is integrated from the start and becomes differentiated with development (Gibson, 1969). Thus, infants use integrated, redundant, or global information across the senses to detect invariant properties of multimodal events (Bahrick & Pickens, 1994; also see Thelen & Smith's, 1994, concept of reentry for a neural argument supporting this view). Redundant information includes temporal synchrony, spatial colocation, shared rhythm, tempo, and intensity shifts. This type of redundancy is available in the sound and sight of a talking person (Kuhl & Meltzoff, 1988). The movements of the mouth and lips are synchronous with the speech sounds. The redundancy specifies that the sound and sight belong together (Bahrick & Lickliter, 2000), and sets the stage for further processing of auditory–visual relations, including arbitrary word–object relations.

Recently, Gogate and Bahrick (1998) demonstrated that infants rely on intersensory redundancy to learn arbitrary syllable–object relations. In an infant-controlled habituation procedure, infants received two alternating video displays of the syllables /a/ and /i/, paired with a toy porcupine and a crab or a lamb

chop and a star, in one of three conditions (Table 1): (a) The syllables were vocalized in synchrony with moving objects (moving-synchronous condition), (b) they were vocalized out of phase with the movements of the objects (moving-asynchronous condition), or (c) they were vocalized when the objects were static (still condition). Infants' learning of the syllable–object relations was tested using a modified switch method (Bahrick, 1992, 1994; Stager & Werker, 1997; for arbitrary relations between visual attributes see Younger & Cohen, 1983) where the arbitrary relations between the objects and syllables were switched or mismatched. For example, if infants received a crab with /a/ and a porcupine with /i/ during the habituation phase, they received the crab with /i/ and the porcupine with /a/ during the switch or mismatch test trials. Infants were expected to look longer to the switch trials compared to no change (matching) trials, where the syllable–object relations remained unaltered, if they had learned the arbitrary relations during habituation. Results indicated that only the infants in the moving-synchronous condition looked longer to the switch trials than to the no-change trials (Figure 1). Because the only difference between habituation and switch trials was the change in syllable–object relations, infants' longer looking in this condition indicated detection of the switch in the objects' relation to the syllables. Thus, at least by 7 months, infants use redundancy (temporal synchrony) between spoken syllables and an object's motions to learn arbitrary syllable–object relations. Research has also demonstrated learning of syllable–object relations in the absence of temporal synchrony at least by the age of 14 months (Werker et al., 1998). Thus, intersensory redundancy serves to highlight the connection between vocalizations and objects, specifying the link between referent and object and providing one of the earliest bases for learning

TABLE 1
Summary of Procedures Used for Infants in Gogate and Bahrick (1998) and in Experiment 1

Procedure	*Stimuli*	*Source*
Habituation training		
Infant-controlled habituation (synchronous, asynchronous, or still condition; alternating trials)	Two syllable–object pairs	Gogate & Bahrick (1998)
Habituation test		
Switch trials (difference score between no-change control and switch trials)	Two altered syllable–object pairs	Gogate & Bahrick (1998)
10-min memory test		
Two-choice intermodal preference (matched to infants' habituation condition)	Simultaneous object displays with one or the other syllable in a random order	Experiment 1, this study

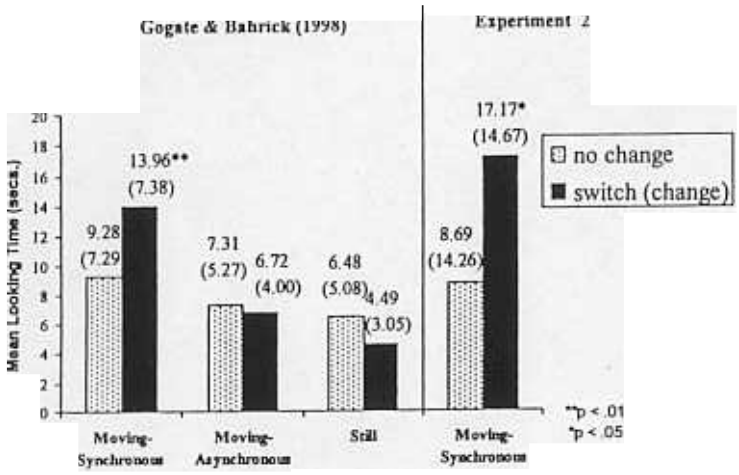

FIGURE 1 Mean looking (and standard deviations) to syllable–object pairs following habituation under the moving-synchronous, moving-asynchronous, and still conditions as a function of trial type. *Note.* The left side of this figure is adapted from "Intersensory Redundancy Facilitates Learning of Arbitrary Relations Between Vowel Sounds and Objects in Seven-Month-Old Infants," by L. J. Gogate and L. E. Bahrick, 1998, *Journal of Experimental Child Psychology, 69,* p. 141. Copyright 1998 by Academic Press. Adapted with permission.

and remembering for these relations. Research has also demonstrated that mothers provide a great deal of temporal synchrony and spatial colocation between words and objects when they teach the names for novel objects and actions to their 5- to 8-month-old infants (Gogate, Bahrick, & Watson, 2000; Gogate, Betancourt, Bolzani, & Watson, 2000). As infants develop language and no longer need synchrony to highlight word-referent relations, but can detect these relations on their own, mothers' use of synchrony decreases, and naming in the presence of static objects increases. Thus, intersensory redundancy is provided when it is most needed early on and can facilitate the early detection of word–referent relations. Infants must further differentiate, relate, and remember arbitrarily paired words and objects.

Contrary to our view that the senses are integrated from the start and become differentiated with experience (Gibson, 1969), the associationist view purports that the senses are separate from birth and become integrated with experience (e.g., Birch & Lefford, 1967). Thus, infants come to relate words and objects by association when they see an object and hear a word together. The process of differentiation we propose differs from and complements the process of association in many ways. First, it provides an explanation for why and when some concurrent sounds and objects are perceived as related and others are not. Accordingly, it proposes a developmental progression where early detection of redundant information, such as synchrony, facilitates eventual differentiation of embedded arbitrary relations (Bahrick & Pickens, 1994). Intersensory redundancy can be perceived by detecting invariant relations with a unified perceptual system through the process of differentiation and requires little specific learning (e.g., Bahrick & Lickliter, 2000; Gibson, 1969). In contrast, arbitrary relations must be learned through experience by relating information across two sense modalities that share no intrinsically similar properties. Thus, intersensory redundancy can be considered as a special kind of cooccurrence where the same information occurs in two modalities simultaneously. Detection of this redundancy organizes early perceptual development, allows infants to detect that objects and sounds belong together, and eventually enables infants to relate meaningful modality-specific components. In this way, differentiation and association can be seen as complementary processes.

Lexical development also entails memory for word–referent relations. When an adult names an object from an array of objects and events, infants' memory for a specific word–object relation can facilitate lexical comprehension. Thus, in addition to merely detecting the mismatch between words and objects, infants must search for the correct objects when given the words. Although prior research has looked at the conditions that facilitate syllable–object mapping (Gogate & Bahrick, 1998), the issue of whether infants remember these pairings has never been investigated. Under what learning conditions do infants remember word–object relations, and does memory last across a period of days? To address these questions, we conducted two experiments. In Experiment 1, we tested the infants who participated in Gogate and Bahrick's study in a follow-up intermodal preference procedure. Researchers have used several versions of this method to study older infants' word-to-object mapping (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; Schafer & Plunkett, 1998). On hearing a word, infants were expected to search for and look first at the object (from two choices) that matched with the word. This test of memory, better than a repeated but delayed presentation of the switch and no-change trials, mimics the word learning environment where infants might need to select one of two visible objects that is being named. Because learning occurred only in the moving-synchronous condition of Gogate and Bahrick's study, those infants alone were expected to remember the relations 10 min later. Alternatively, the different conditions could have resulted in different levels and rates of learning. Thus, in the asynchronous or still condition, although infants did not look longer to the switched displays after habituation, lower levels of or slower learning of the syllable–object relations might result in familiarity and matching on the memory test. Therefore, we tested infants' memory for these relations under all three conditions. In Experiment 2, we tested a second group of infants to determine if memory lasted for a longer period.

EXPERIMENT 1

Method

Participants. The forty-eight 7-month-old infants ($M = 220$ days, $SD = 5.14$ days) who had completed Gogate and Bahrick's (1998) experiment participated. These full-term, healthy infants were recruited from local birth records. Their parents were middle class, with 12 or more years of education. Infants were required to complete at least 8 of 12 trials to be included in the final sample. Two participants in the moving-synchronous condition did not meet this criterion due to excessive fussiness. Thus, the final sample consisted of 14 infants in the moving-synchronous condition and 16 infants each in the moving-asynchronous and still conditions.

Stimuli. The video displays consisted of a plastic crab and a porcupine or a plastic lamb chop and a wooden star, each paired with /a/ or /i/, in one of three conditions (identical to Gogate & Bahrick, 1998). Infants easily distinguish these syllables (Kuhl & Meltzoff, 1988). A female actor (whose hand alone was visible on the videos) uttered the syllables in infant-directed speech to resemble isolated monosyllabic words. The syllables were presented in an erratic and unpredictable tempo at 26 tokens per minute. The rhythm, tempo, and intonation patterns of the syllables were controlled across conditions.

For the moving-synchronous display, each object was moved in synchrony with each syllable. The hand-held objects were randomly moved forward and back or laterally as if showing them to the infant. The mean time lag between syllable onset and object motion was .45 sec ($SD = .19$), and syllable offset and object motion was .04 sec ($SD = .11$) across 20 random occurrences. For the moving-asynchronous condition, each object was moved out of synchrony with each syllable. The mean time lag between syllable onset and object motion was .82 sec ($SD = .68$), and syllable offset and object motion was .90 sec ($SD = .86$) across 20 random occurrences. For the still condition, each object was static and accompanied by the same erratic series of syllable tokens.

Procedure and apparatus. Following habituation under a moving-synchronous, moving-asynchronous, or still condition (Gogate & Bahrick, 1998; see Table 1) and a delay of 10 min (indicated by a timer), infants were brought from the waiting room to the testing room for the two-choice intermodal memory test. Infants were seated 55 cm away and equidistant from two adjacent 20-in. color monitors (Sony KV20M10). They received two identical blocks of six 15-sec trials under their prior habituation condition (synchronous, asynchronous, or still). On each trial, infants heard a series of /a/ or /i/ from a central speaker and watched side-by-side displays of the two distinctive objects. Infants' attention was centered before each trial using bells located between the monitors. For the moving-synchronous test, the two objects were played moving in synchrony with one another and in synchrony with each syllable. For the moving-asynchronous test, the two objects moved out of synchrony with one another and with each syllable. For the still test, the objects were static while each series of syllable tokens was presented. On each trial, the sounds 'a' or 'i' preceded the onset of the visual event by approximately 4 sec (two tokens) before the objects appeared on the monitors. Once the objects appeared, infants were expected to search for and select the matching display if they remembered the syllable–object relations learned during habituation. The lateral positions of the displays were counterbalanced across the two blocks. The order of syllable presentation was randomized but identical across blocks.

Trained observers, blind to the lateral positions of the displays, recorded infants' looks to the displays from one of two peepholes situated behind the monitors. The mean proportions of first looks (PFL) to the matching object display were measured. PFLs were obtained by dividing the sum of trials where infants looked first to the matching display by the total number of trials. The mean correlation between two observers' PFLs calculated for 16 infants (33%) was .91 ($SD = .09$).

Results and Discussion

Infants in the moving-synchronous condition alone remembered the syllable–object relations. Their PFLs to the matching object display differed significantly from chance (50%) across the two blocks of trials, $t(13) = 2.29, p = .039$, and on the first block of trials considered alone, $t(13) = 2.92, p = .012$, whereas that of the other groups did not ($ps > .1$). Further, an analysis of variance (ANOVA) of the PFLs across the two blocks of Trials × Condition (3) was significant, $F(2, 43) = 4.45, p < .02$.[1] A post hoc multiple comparison t test (Scheffé's two-tailed $p < .05$) revealed that infants in the moving-synchronous condition looked first to the matching object displays more often than infants in the still or moving-asynchronous condition (Figure 2, Experiment 1). Infants showed no stimulus or right-or left-side bias within condition ($ps > .1$).

Further, we compared individual participants' success in syllable–object matching (PFLs above and below 50% treated as a dichotomous variable) across conditions. In the synchronous condition (10 of 14), infants looked first to the

[1]Except for the first trial on each block of six trials, infants knew on which monitor each object was to appear. Analyses of these first trial proportions of first looks for each block versus chance (50%) revealed at-chance performance regardless of condition. Because at-chance performance does not affect the significance levels of the results, these first trial proportions were included in the main analyses of the experiments. The proportions of total looking time and longest looks to the matching displays were also calculated across blocks. These measures did not differ by condition ($ps > .1$).

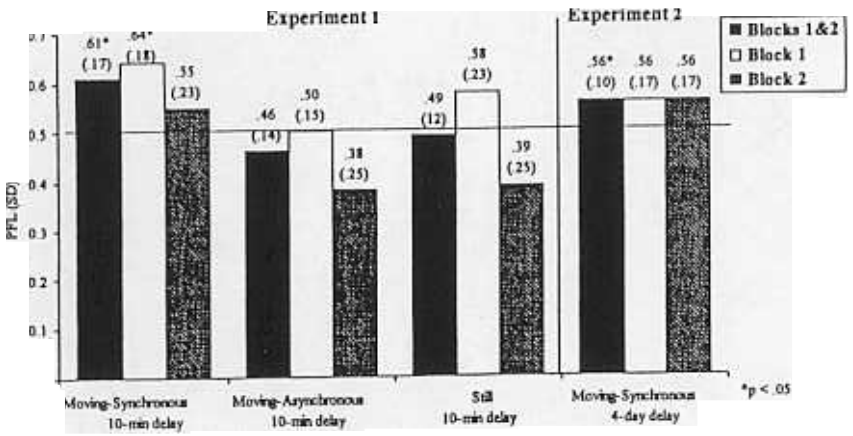

FIGURE 2 Proportion of first looks (and standard deviations) to the syllable-matched display (proportions of first looks) on the intermodal memory tests under the moving-synchronous, moving-asynchronous, and still conditions.

matching displays more often than in the asynchronous (4 of 16; pooled $z = 2.54, p = .006$) or still conditions (6 of 16; pooled $z = 1.86, p = .03$).

In summary, given intersensory redundancy during learning, 7-month-olds remembered the arbitrary syllable–object relations 10 min later. After infants heard the syllables 4 sec prior to viewing the now familiar object displays, they oriented to the matching display first. These results are consistent with prior findings, showing fast mapping of familiar words onto objects by 15- and 24-month-olds (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998). Given these results, we conducted a second experiment to test whether infants would remember the syllable–object relations longer (4 days) if temporal synchrony were provided during learning.

EXPERIMENT 2

Method

Participants. Sixteen 7-month-olds ($M = 220$ days, $SD = 3.11$ days; 8 boys and 8 girls) participated in two visits. The recruitment criteria were identical to that of Experiment 1. Eight additional infants were excluded from the final sample due to experimenter error ($n = 1$), equipment failure ($n = 1$), fatigue ($n = 1$), external interference ($n = 3$), and failure to return for the second visit ($n = 2$).

Procedure and apparatus. On the first visit, infants were habituated and tested under the moving-synchronous condition of Gogate and Bahrick's (1998; also see Table 2) earlier study. Infants were seated in an infant seat facing a TV monitor. Two syllable–object displays were played one at a time on the monitor from one of two VCRs (Panasonic AG 7750). Infants received the alternating displays until their looking on two consecutive trials was less than 50% of their looking on the two initial trials. Next (after two posthabituation trials to control for regression effects), they received the two no-change (match) and two switch test (mismatch) trials counterbalanced for order. Again, infants were expected to look longer to the switch trials compared to the no-change trials if they had learned the syllable–object relations during habituation. Infants controlled the length of each trial. A trial began when infants fixated on the monitor and ended when they looked away for 1.5 sec or longer. Trained observers, blind to the condition, recorded infants' looking to the displays (seconds). The mean correlation between two observers' scores for 6 out of 16 participants (37.5%) was .97 ($SD = .03$). The infants returned after a mean interval of 4 days (range = 2–7 days, $SD = 2$ days) for the second visit and received the memory test identical to the moving-synchronous condition of Experiment 1. The mean correlation between two observers' proportions of infants' first looks to the matching display (PFL) calculated for 7 out of 16 infants (44%) was .91 ($SD = .02$).

Results and Discussion

A mixed ANOVA assessed infants' looking (seconds) as a function of trial type (switch, no change), type of syllable–object pairing (4), and order of presentation of trial type (2). The analysis revealed a significant effect of trial type, $F(1, 8) = 6.5, p = .034$, but not of syllable–object pairing, $F(3, 8) = .70, p > .1$; order of test presentation, $F(1, 8) = .25, p > .1$; or interactions between factors, $ps > .1$. These results rep-

TABLE 2
Summary of Procedures Used for Infants in Experiment 2

Procedure	*Stimuli*
Habituation training	
Infant-controlled habituation (synchronous condition; alternating trials)	Two syllable–object pairs
Habituation test	
Switch trials (difference score between no-change control and switch trials)	Two altered syllable–object pairs
4-day memory test	
Two-choice intermodal preference (matched to infants' habituation condition)	Simultaneous object displays with one or the other syllable in a random order

licate those of Gogate and Bahrick (1998). Infants looked significantly longer to the switch trials than to the no-change trials (Figure 1, Experiment 2), showing learning of the syllable–object relations after habituation to temporally synchronous events. A paired t test comparing infants' looks to the first versus the second switch trial showed no difference ($M = .32$ sec), $t(15) = .07, p > .1$. Thus, infants attended to the redundant information and arbitrary relations across both syllable–object pairs. An analysis of individual participants' scores revealed that 11 of the 16 infants looked longer to the switch than to the no-change trials.

On the memory test 4 days later, infants looked first more often than chance (50%) to the matching object display across the two blocks of trials ($M = .56$), $t(15) = 2.57, p < .025$ (Figure 2, Experiment 2). [2] Secondary analysis of the PFLs revealed no visual preference for the right or left position of display, stimulus bias, or a difference between blocks ($ps > .1$). These group results show that synchrony facilitated long-term memory for syllable–object relations. An analysis of individual infants' PFLs revealed, however, that 10 of the 16 infants looked first to the syllable-matched object more often than chance (50%), suggesting emergent memory for syllable–object relations. Infants' PFLs and retention interval were not correlated, Pearson $r(15) = -.40, p = .12$.

GENERAL DISCUSSION

The results of Experiments 1 and 2 demonstrate that 7-month-old infants remember arbitrary syllable–object relations 10 min and 4 days after the original learning occurred under the moving-synchronous condition. They showed evidence of memory by looking first to the matching object on hearing a syllable in a two-choice intermodal procedure. This extended retention is particularly impressive given that infants received only a relatively brief exposure to the two syllable–object displays (Experiment 2; $M = 154.76$ sec, $SD = 81.12$ sec). These findings demonstrate that preverbal infants have important requisite capabilities that provide a basis for lexical development and the eventual understanding of word meaning. The infants remembered the relations by selectively attending to and perceiving the redundant information between an utterance and a moving object.

These findings with 7-month-olds also provide the earliest evidence for learning of and memory for novel arbitrary syllable–object relations. (In contrast, 6-month-olds remember and match familiar words such as *mommy* and *daddy* with familiar concepts such as their own mother's and father's face; Tincoff & Jusczyk, 1999.) As young as 7 months, infants have the capability for recognizing recently learned syllable–object relations as long as 4 days later, providing a basis for the

[2]The proportions of total looking time and longest looks to the matching displays, calculated across blocks, did not differ from chance (50%).

development of a referential system. Prior to symbolic–lexical development, infants detect and remember word–object relations by attending to the intersensory redundancy between the syllables and movements of the objects provided by adults. Redundancy such as temporal synchrony appears to orient infants to the relation between the spoken word and the object referent at a time when infants do not yet know that words go with or stand for objects. Abstraction of these relations typically emerges in a social context, and temporal synchrony between word and gesture is prevalent in natural communication. Further, mothers use it to teach their preverbal infants word–referent relations (Gogate, Bahrick, & Watson, 2000), and infants learn these relations from their mothers (Gogate, Betancourt, et al., 2000). Therefore, adults' temporal coordination between vocalization and gesture is important for specifying which words and objects go together and for providing an important basis for early word learning, memory, and comprehension (Gogate et al., 2001).

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