JOURNAL OF EXPERIMENTAL CHILD PSYCHOLOGY **31**, 279–299 (1981)

The Infant's Acquisition of Knowledge of Bimodally Specified Events

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Four-month-old infants viewed, for a duration of several minutes, two objects that bounced in synchrony with two percussion sounds. This synchrony was the only information tying each sound to its respective object. During the viewing the infants learned about the relationships between sound and object. Learning was revealed in two ways. In a search test, infants looked for an object when its sound was played. In a transfer test, infants' declining interest in a sound presented alone generalized to the visible object that the sound specified. Studies that reversed the spatial locations of the objects revealed that sound–object learning, rather than place or response learning, guided infants' perceptual exploration.

Most objects and events can be perceived through more than one sensory modality. A single object can often be seen, heard, and felt, and the relationship between its visible, audible, and tangible properties is usually predictable. Human adults are aware of many of these intermodal relationships. They know, for example, coal that looks red usually feels hot, creatures making buzzing sounds can give painful stings, a crash of thunder usually follows a streak of lightning. Adults use such knowledge in at least two ways. First, knowledge of intermodal relationships can direct exploration. When adults hear a certain buzz, their visual search for its source can be guided by knowledge of the appearance of a bee. Second, knowledge of intermodal relationships can extend one's perception of objects. When adults detect a bee by listening alone, they know a great deal about how that creature looks and how its sting feels.

What are the origins of the adult's knowledge of intermodal relationships? Recent research suggests that some of this knowledge is given at

I thank two anonymous reviewers for their suggestions concerning the data analysis. This research was supported by biomedical research funds from the University of Pennsylvania and by a grant from the National Institute of Child Health and Human Development (HD-13428). Portions of this paper were presented at a meeting of the International Conference on Infant Studies, Providence, March 1978.

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0022-0965/81/020279-21$02.00/0

birth. For example, 1-month-old infants can detect a relationship between the sight and the feel of a sphere or cube (Meltzoff & Borton, 1979), and newborns respond, on some level, to a relationship between an object's visible and audible location (e.g., Butterworth & Castillo, 1976; Muir & Field, 1979; Wertheimer, 1961). But some knowledge of intermodal relationships is surely acquired. An intermodal relationship may be quite arbitrary. There is little reason why the sound of a certain chime should come from an object that looks like a grandfather clock, or why a certain stinging pain should be produced by a buzzing bee. Our ability as adults to appreciate these relationships would seem to depend on learning. It is of interest to ask how this learning takes place and when it begins.

Recent studies suggest that learning about intermodal relationships starts early in life. Most experiments have focused on infants' knowledge of the relationship between the sight of a parent's face and the sound of his or her voice. Infants of various ages have been presented with the face of the mother and the face of a second person—the father or a female stranger—paired with the mother's or the other person's voice. Although the results of different studies have conflicted in some respects, all have indicated that infants below one year of age respond to appropriate face–voice pairings (such as the mother's face with her voice) differently than to inappropriate pairings (such as the mother's face with a stranger's voice). Infants have been reported to show signs of conflict when presented with inappropriate face–voice combinations (Carpenter, cited in Bower, 1979; Cohen, 1974; Lewis & Hurowitz, Note 1; see Spelke & Cortelyou, 1980, for a review). Furthermore, infants presented with the faces of two parents accompanied by one parent's spatially centered voice have been reported to look preferentially to the parent whose voice they heard (Spelke & Owsley, 1979). All these studies suggest that infants learn about the relationship between a parent's face and voice.

Two experiments have investigated the acquisition by infants of knowledge about auditory–visual relationships. Lyons-Ruth (1977) familiarized 4-month-old infants with a sounding, visibly oscillating object. Optic and acoustic stimulation from the object were united in three ways: they uniquely occurred together in time, they were presented in the same spatial direction, and they were temporally synchronized. Learning was subsequently tested by playing the object's sound in a new direction, where the same or a different object was visible. Infants averted their heads from the novel object, a response which was interpreted to reflect a violated expectation that the familiar object would be encountered in the direction of its sound. Lawson (1980) reported similar findings in experiments using a visual preference test. In two of her experiments, infants of 6 months were familiarized with a spatially related sound and object. During a subsequent test, these infants looked more to the familiar object than to a novel object when the sound was played.

The present experiments further investigated the ability of 4-month-old infants to learn about relationships between the audible and visible properties of inanimate objects. They probed whether learning would take place in a brief laboratory session in which infants viewed an object moving and sounding in temporal synchrony. Furthermore, these experiments investigated whether infants could use what they learned about auditory–visual relationships in the same ways adults do. I asked whether knowledge about auditory–visual relationships could (a) guide infants to look for an object they hear and (b) allow infants to perceive an object with certain visible characteristics solely by listening.

In four experiments, infants were familiarized with moving, sounding objects for 200 sec. In the familiarization period, infants were shown two moving objects, side by side. In succession they heard two different sounds, each synchronized with one of the objects. Only this synchrony tied a sound to one of the objects: The sound–object pairings were arbitrarily chosen, and the sounds were spatially centered between the objects. This period was followed by an episode that tested the infant's ability to learn the relationship between the audible and visible properties of each object.

The experiments tested learning in different ways. Experiment 1 used a search test. Infants briefly heard the sound of one object while both objects were in view. This sound was synchronized with neither object, so no stimulus information united the sound preferentially with either visual display. The experiment investigated whether infants would look to the object that had formerly been synchronized with that sound. Only knowledge, acquired during the preceding familiarization period, could guide such looking.

Experiment 2 investigated whether infants could use knowledge of auditory–visual relationships to identify, by listening alone, an object with certain visible properties. The experiment used a transfer test. Infants heard one of the sounds that had been played during familiarization, but this sound was now presented without any visual display. Following this presentation, the two objects appeared silently, side by side. I investigated whether infants would exhibit a novelty preference for the object that had *not* been synchronized with the preceding sound. Such a preference would indicate that when infants heard the sound alone, they detected an object with visible properties.

In Experiments 1 and 2, each object appeared consistently to the infant's left or right. Infants could learn that each sound specified an object with particular visible characteristics or an object in a particular location. Indeed, infants could even learn to relate sounds to their own actions: they might learn to associate one sound with turning to the left and the other with turning to the right. Experiments 3 and 4 attempted to distinguish between these possibilities by presenting infants with tests in which the locations of the two objects were reversed. In Experiment 3, the period of familiarization was followed by a search test, while in Experiment 4, the familiarization period was followed by a transfer test. Thus Experiments 3 and 4 investigated whether learning about sound–object relationships, rather than place-learning or response-learning, can guide infants' looking for an object that they hear and their perception of an object by sound alone.

EXPERIMENT 1

The first experiment made use of a test which has been employed in prior studies of auditory–visual perception (Spelke, 1979b). In the prior research, infants had been presented with two objects bouncing silently. On repeated trials, the experimenter attempted to draw their attention between the objects by flashing a row of colored lights, and then one of the sounds—synchronized with one of the two objects—was played through a central speaker. The infants tended to look toward the object that moved in synchrony with the sound. This search pattern indicated that infants are sensitive to the synchrony of sound and visible movement, and they, like adults, tend to look for an object when its sound is played. In the present experiment, the same search test was given, but the two sounds were not synchronized with either object. Thus, no immediately available information tied each object to a sound. The test followed a period of familiarization in which each sound was synchronized with one object. It was expected that infants would search for the object that had formerly been synchronized with a sound. In order to do this task, infants had to use knowledge acquired during familiarization to guide their looking.

Method

Subjects. Sixteen infants, aged 3 months, 21 days to 4 months, 15 days (mean, 4 months, 4 days) participated in the experiment. Three additional infants failed to complete the experiment due to fussiness. Infants were healthy and full-term and lived in Philadelphia, Pennsylvania, or its suburbs. The sex of the infants was not controlled in this or any other study. Analyses of the results of 11 such studies of auditory–visual perception or learning have revealed no reliable effects of sex in any study on any measure (Spelke, Note 2).

Display materials and apparatus. Four events, filmed in color and in sound, served as the stimulus displays. One film depicted a yellow toy kangaroo bouncing on a grassy lawn at the regular rate of one bounce every 2 sec. A gong, produced by hitting a shoe against the metal lid of a large oil drum, was played whenever this animal landed on the ground. A second film depicted the kangaroo bouncing on the lawn at the same tempo, in synchrony with a thump, produced by hitting the shoe against a wooden box. The third film depicted a gray toy donkey on the lawn, bouncing at the same tempo of once per 2 sec and accompanied by the gong, while the fourth film depicted the donkey bouncing at this tempo in synchrony with the thump. In addition to these four sound films, tape recordings of each sound track were made for presentation during the test.

Two films—one of the kangaroo and one of the donkey—were rear-projected side by side onto a translucent screen. The projected images each measured 36 by 33 cm and were projected 8 cm apart. The infant sat in a reclinable seat, eye-level with the projected films at a distance of 40 cm. When the films were shown side by side, the animals' movements were out of phase with each other. This was accomplished by advancing one reel of film slightly relative to the other. Furthermore, the phase relations between the films tended to change unsystematically over the course of the familiarization period. This occurred because the projectors were not mechanically synchronized.

Each filmed or tape-recorded sound track was played through a speaker centered between the events and placed 1.5 m behind the projection screen. The volume of the sound tracks and tape recordings averaged 66 db (A) at the infant's location, while the ambient noise in the room averaged 42 db when the films were projected without sound. A vertical row of colored lights, centered between the events, could be flickered to attract the baby's attention. The infant's looking to each object could be monitored by live observers, who watched him or her through peepholes below the screen and recorded looking to the left and right onto an event recorder by depressing buttons. The onset and offset of each sound track were also marked on the event recorder.

Design and procedure. Each infant participated in a familiarization period followed, after 5 minutes, by a search test. The familiarization period consisted of two 100-sec sessions. During both sessions, two films were projected side by side. Each infant viewed one film of each animal. One animal moved in synchrony with the thump sound and the other with the gong sound. Infants heard one sound track during the first session, the other sound track during the second session. These were played from the projectors. Half the infants viewed the kangaroo synchronized with the gong and the donkey synchronized with the thump; the others viewed films with the reverse sound–object pairing. The lateral position of these films and the order of sound tracks were counterbalanced across infants.

During the search test, all infants were presented with the same films, in the same lateral positions, as during the period of familiarization. The films were accompanied by a series of brief, tape-recorded segments of each sound track. The tape recordings were played through the same speaker, at roughly the same volume as the original sound tracks. The recording began at haphazardly chosen times, so the phase relations of each recorded sound with each visible event varied unsystematically. Since both filmed objects moved at the same rate, no information—temporal or spatial—united the tape-recorded sound with either visible event during the search test. At the start of the search session, the two films were projected silently and the colored lights were flickered between them for 1 sec. Then the lights went off and the tape-recorded thump or gong sound was heard for 5 sec. The sound began whether or not the infant was looking at the lights. When the sound ended, the light was flashed again for 1 sec and a second tape-recorded sound track was played. Infants continued to receive search trials until they became fretful or until the 200-sec films had ended. Between 8 and 12 trials were given for each tape-recorded sound track. The order of sound tracks was random with the restriction that neither sound track was played more than three times in succession. A different order was used for each infant.

Looking was monitored during the familiarization and the test episodes by two different observers, neither of whom was aware of the lateral position of the object that went with each sound. Interobserver reliabilities were expressed as the number of seconds of observer agreement divided by the number of seconds of agreement plus disagreement. These ranged from 80 to 97% and averaged 89% during the preference episode; they ranged from 76 to 97% and averaged 87% during the search test. Looking times were reduced from the event recorder by assistants who scored looking to the left film, to the right film, or to neither film, in ignorance of the direction of each sound-related object.

Dependent measures and data analysis. During the preference episode, the duration of looking to the aurally synchronized and nonsynchronized objects was measured separately for the two 100-sec periods. Mean looking time to the synchronized and nonsynchronized objects during the two periods was calculated.

The principal dependent measure was the number of infants looking longer to the aurally specified objects; this was analyzed by a binomial test. Differences in looking times to the synchronized and nonsynchronized objects were also analyzed by t tests for correlated samples.

Search trials were subjected to two kinds of analysis. A preliminary analysis included the data from every trial administered to an infant, regardless of where the infant was looking at the beginning of the trial. For each infant, a count was made of the number of trials during which he or she responded to a sound by looking to the appropriate object, and the number of trials during which he or she looked to the inappropriate object. A trial was scored as a response to the appropriate object if: (a) the infant began the trial with a look to the appropriate object and never turned to the other object; (b) the infant began a trial with a look to the inappropriate object and subsequently turned to the appropriate object; or (c) the infant began a trial looking to neither object and turned first to the appropriate object. A trial was scored as a response to the inappropriate object if infants showed any of the three opposite looking patterns.

The principal analyses included only data from trials that began while the infant was looking to neither film. An average of 9.9 search trials per infant (67% of the trials administered) were included in these analyses. Four measures of searching for the sound-appropriate and for the inappropriate object were calculated from these trials. For the *first look* measure, we calculated the number of trials on which the infant looked toward the appropriate object before he or she looked toward the inappropriate object, and the number of trials on which he or she looked to the inappropriate before the appropriate object. A look was counted only if it occurred within 5 sec of the sound onset. For the *eventual look* measure we calculated the number of trials on which the infant looked at all, first or second, to the appropriate or inappropriate object. For the *latency* measure we assessed the mean duration of time that elapsed between sound onset and the first look to the appropriate object, and similarly for the inappropriate object. A latency score of 5 sec was assigned to any usable trial for which no look occurred to the object in question within 5 sec. Finally, for the *duration* measure, we assessed the mean duration of looking toward the appropriate object during the 5-sec period following sound onset, and similarly for the inappropriate object. A duration score of 0 sec was assigned to any trial for which no look occurred to the object in question within 5 sec.

The number of infants who searched more for the appropriate than for the inappropriate object was calculated for the preliminary analysis and for each of the four principal search measures. These measures were then analyzed by binomial tests. To support these analyses, differences between looking to the appropriate and to the inappropriate objects were also analyzed by correlated t tests.

Results

Familiarization period. Mean looking times to the synchronized and nonsynchronized objects are given in Table 1. Infants tended to look longer to the aurally specified object during the first preference session and to the nonspecified object during the second session. Nine of the sixteen infants preferred the synchronized object on the first session, 5 on the second session, and 11 showed a mean preference for the synchronized object on both sessions combined. None of these preferences are significant, $p > .10$. There was no preference for either side or either animal.

Search test. The results of the search test are given in Table 2. On the preliminary analysis, infants responded to the sound-appropriate object on a greater average number of trials than to the inappropriate object. Ten individual infants showed this tendency, whereas four responded more to the inappropriate object, $p < .10$.

TABLE 1

VISUAL PREFERENCE FOR AURALLY SYNCHRONIZED EVENTS: EXPERIMENT 1

	Looking time (sec), synchronized event	Looking time (sec), nonsynchronized event	$t(15)$
Session 1	48.58	30.61	1.50
Session 2	29.70	39.19	0.92
Mean	39.14	34.95	0.76

On the principal measures, infants tended to look first, look eventually, and look with a shorter latency to the object that had formerly moved in synchrony with each sound. They did not tend to look to a sound-appropriate object for a longer duration. Only the first look measure gave reliable results on the binomial test. Nine infants looked first more often to the appropriate object and one showed the reverse tendency, $p < .02$. The other sign test results were not significant. With ties eliminated, 8 of 11 infants looked eventually more often to the appropriate object, 10 of 16 looked to that object with shorter latency, and 7 of 16 looked to that object for a longer duration, all p's $> .10$. Again there was no tendency to look more to either side or to either animal.

Discussion

When infants heard a sound during the search test, they appeared to look for the object with which that sound had formerly been synchronized, even though no immediately available information united the sound and the object. The results suggest the infants learned about the relationship between each sound and its synchronized object. Learning seemed to occur during a period of familiarization which lasted only 200 sec, when only the synchrony of sounds and visible movements tied each sound track to one filmed event.

The results of the preference and search episodes closely agree with those of earlier studies of intermodal perception using this method and these displays (cf., Spelke, 1979b). Infants generally exhibit some pref-

TABLE 2

VISUAL SEARCH FOR SOUND-APPROPRIATE OBJECTS: EXPERIMENT 1

Search measure	Appropriate object	Inappropriate object	$t(15)$
Preliminary measure (No. trials)	7.25	5.94	2.47*
First look (No. trials)	4.94	3.88	2.72**
Eventual look (No. trials)	6.62	6.12	1.92*
Latency (sec)	2.63	2.91	1.75*
Duration (sec)	1.05	1.27	−0.92

* $p < .05$, one-tailed.
** $p < .01$, one-tailed.

erence for these aurally synchronized moving objects, especially during the first preference session, but this preference is rarely reliable. Greater and more consistent preferences for acoustically synchronized objects have been obtained in studies where the objects were people (Spelke & Cortelyou, 1980) or toys moving in more interesting, irregular patterns (Spelke, 1976; Bahrick, 1979). On search tests, infants generally look for an object when its sound is briefly played, according to the first look, eventual look, and latency measures, but not the duration measure. Thus, infants in the present study searched much as infants have done in previous research, despite the fact that sounds and visible movements were not synchronized in the present search test, as they had been in the earlier studies.

The results of Experiment 1 appear to support three conclusions. First, infants are sensitive to the synchrony of sounds with the movements of visible objects. This finding corroborates that of earlier research (Spelke, 1979b). Second, infants learn very rapidly about the relationship between a sound and a visible object. Third, infants can use what they have learned to direct their visual exploration of an object that they hear. Specifically infants can look for an object when they hear its sound, even though no immediately given temporal or spatial information unites the sound and the object.

EXPERIMENT 2

Experiment 1 suggested that infants can use knowledge of an auditory–visual relationship to guide their exploration. Experiment 2 investigated whether they can use such knowledge to identify, by listening alone, an object with certain potentially visible characteristics. The experiment consisted of a familiarization period followed by an intermodal transfer test. The test is adapted from a method used in studies of visual-haptic perception (Gottfried, Rose, & Bridger, 1977). Gottfried and his colleagues familiarized infants with an object by touch alone: the infants explored with their hands an object they could not see. The infants were then given a visual preference test. Two objects were presented side by side: the object that the infants had felt and a different object with a different shape. Infants of 12 months exhibited a preference for the object which they had *not* previously felt. Thus, a familiarization with the touch of an object systematically influenced visual exploration. The existence of intermodal transfer provided evidence that infants could perceive some spatial properties of an object both by touching and by looking.[1]

[1] Other investigators have also found evidence for haptic-to-visual transfer of a shape discrimination in infancy. In some of these studies, however, infants manifested this transfer by reliably preferring the familiar object in the transfer test (Meltzoff & Borton, 1979; Ruff & Kohler, 1978). The conditions under which one obtains a novelty preference versus a familiarity preference are not clear. Novelty preferences may be observed more frequently with older infants, longer periods of familiarization, and/or less interesting displays.

The present research followed the method of Gottfried *et al.* (1977) with two principal modifications. First, it focused on auditory–visual perception: familiarization with the sound of an object was followed by a visual preference test. Second, and more important, the transfer test assessed infants' knowledge of intermodal relationships, not their perception of amodal properties of an object such as its shape. No spatial or temporal information united the sight and sound of an object during this test. Before this episode, however, infants had received a familiarization period in which that sound had been synchronized with one of the two objects. (A different sound had been synchronized with the other object.) Infants were expected to have learned about the sound–object relationships. When they subsequently heard one sound by itself, they were expected to perceive it as the sound of a particular object, with definite visible attributes. In consequence, presentation of the sound alone was expected to lead to a novelty preference for the nonspecified object.

Method

Subjects. Sixteen infants, aged 3 months, 17 days to 4 months, 26 days (mean, 4 months, 6 days) participated in the experiment. Eight additional infants failed to complete the experiment due to fussiness. All were healthy, full-term, and living in the city or suburbs of Philadelphia.

Displays, design and procedure. The display materials and apparatus were the same as in Experiment 1. Each infant participated in a familiarization period followed, after 5 min, by an intermodal transfer test. The familiarization period was as in Experiment 1. The transfer test began with a 50-sec presentation of one sound track. The sound was played through the same central speaker as during familiarization. It was played in semidarkness, with no accompanying films. A 30-sec preference test immediately followed in which the two films were presented with no accompanying sound. The sound presentation was then repeated for 30 sec using the same sound as before. The test ended with a second 30-sec presentation of the two silent films. The films occupied the same positions during the two preference episodes of the transfer test as during the familiarization period.

The sound–object pairings, the lateral positions of the objects, the order of the sound accompaniments during familiarization, and the sound presented for further familiarization on the transfer test were orthogonally counterbalanced across infants. Thus, the identity and the spatial position of the novel object on the transfer test were counterbalanced as well.

Note, the familiar and novel visual displays were presented to infants for exactly equal amounts of time throughout the study. Only the presentation of their sound tracks differed. Infants could exhibit the predicted preferences between the objects only if the decline of interest in the sound generalized to the object with which the sound had been synchronized.

The infants' looking to the left and right projection screens was monitored throughout the experimental session, including times when the sound was presented alone. Two assistants observed each infant. Interobserver agreement during the familiarization period ranged from 77.8 to 95.8% and averaged 87.0%. Agreement during the sound-alone episodes ranged from 67.3 to 99.7% and averaged 88.2%. Reliabilities during the two silent preference tests ranged from 78.4 to 98.0% and averaged 89.4%.

Dependent measures and data analyses. Total looking times to each side of the screen were calculated separately for the two sound-alone and the two preference test episodes. These calculations were recorded by assistants who were unaware of the location of the novel objects. For each infant, assistants calculated the mean duration of looking to the novel and familiar object during the two visual preference tests. They also calculated the mean duration of looking to the two blank screens during the two sound-alone conditions. The number of infants who looked longer to the novel event was analyzed by a binomial test. Looking times to the two sides were also compared by t tests.

Results

Familiarization period. Looking times during the familiarization period are given in Table 3. Infants tended to look toward the nonsynchronized object on the first session and toward the synchronized object during the second session. Overall, there was no consistent preference for the synchronized objects. A preference for the synchronized object was exhibited by 3 infants during the first session, 10 infants during the second session, and 11 infants during the two sessions combined. Only the first, reverse preference is significant by a two-tailed sign test, $p < .03$. There was no consistent preference for either animal or lateral position.

Transfer test. Mean looking times during the transfer test are given in Table 4. During the sound presentation, there was no consistent tendency to look either toward the screen where the synchronized object had been presented or toward the opposite side. Eight of the infants looked longer in each direction, $p > .10$. When the visual displays appeared, infants

TABLE 3
VISUAL PREFERENCE FOR AURALLY SYNCHRONIZED EVENTS: EXPERIMENT 2

	Looking time (sec), synchronized event	Looking time (sec), nonsynchronized event	$t(15)$
Session 1	32.06	54.50	−2.26*
Session 2	49.51	29.43	2.48*
Mean	40.78	41.96	−0.22

* $p < .05$, two-tailed.

TABLE 4
PREFERENTIAL LOOKING DURING THE INTERMODAL TRANSFER TEST: EXPERIMENT 2

	Auditory periods			Visual periods		
	Looking time (sec), direction of specified object	Looking time (sec), direction of nonspecified object	$t(15)$	Looking time (sec), "old" object	Looking time (sec), "new" object	$t(15)$
Session 1	6.75	5.58	0.46	8.54	15.91	2.16*
Session 2	3.89	4.24	−0.22	6.79	14.99	2.29*
Mean	5.32	4.91	0.21	7.67	15.44	2.62**

* $p < .025$, one-tailed.
** $p < .01$, one-tailed.

looked reliably longer to the novel object: the object that was not specified by the preceding sound. Familiarization with a sound produced a novelty preference between the two succeeding visible objects. Twelve of sixteen infants showed this preference, $p < .05$. There was no preference for either animal or lateral position during the test.

Discussion

The principal hypothesis of this experiment was confirmed. During the intermodal transfer test, presentation of a sound led to decreased interest in the object that it specified. The sound and object were united by no amodal characteristics: they did not move in a distinct rhythm or occupy a single position in space. To these infants, however, each sound was related to one of the objects. They had learned about these relationships during the earlier episode when they watched each object moving in synchrony with one sound. The infants acquired knowledge of the auditory–visual relationships during the period of familiarization.

This finding indicates that infants, like adults, can use what they have learned in order to perceive an object with potentially visible properties by listening alone. After the initial familiarization periods, a "thump" was not simply a sound to these infants: it specified the movements of an object with definite visible characteristics. As the infants' interest in the sound declined, therefore, they also became relatively less interested in the appropriate visible object.

The results of the first session of the familiarization period differed from the results of Experiment 1 and of previous research (Spelke, 1978, 1979b). Since this familiarization period involved the same procedure as in the earlier studies, this is probably a chance effect. The nonsignificant preference for the synchronized film averaged over both sessions, agrees with most of the previous studies.

EXPERIMENT 3

The first two experiments purported to demonstrate that infants acquire knowledge of audio–visual relationships, and that they use such knowledge in the two ways adults do: to guide exploration and to detect objects with visible properties solely by listening. The infants in these studies clearly learned something as a result of looking and listening to synchronized sounds and objects. One might question, however, whether the infants learned about sound–object relationships. Infants might have learned to relate each sound to a position in space, or to a response, rather than to a visible object.

These alternative interpretations are possible because the kangaroo and donkey each occupied a constant position in space, and a constant position relative to the infant, throughout an experimental session. Thus, the location of each object, and the response an infant had to make in order to look at that location, were associated with a sound as much as the visible object was. If infants learned to relate sounds to places, rather than to objects, they might still have performed as they did in the search and transfer tests. In a search test, infants might have looked not for an object but rather for a particular location. In a cross-modal transfer test, prolonged presentation of a sound might have familiarized infants not with a particular object but rather with anything that occupied a particular place. Similarly, infants might have performed as they did by learning to relate sounds to certain responses: turns of the head and/or eyes. In the search test, an auditory stimulus might have elicited a directional response through some conditioning process. A response-learning explanation of the intermodal transfer test is only somewhat more cumbersome. Presentation of a sound alone may have elicited a covert directional response (although it did not elicit an overt one: there were no directional preferences during the sound-alone conditions). Prolonged exposure of the sound then might have led to a decline in that response and preference for some opposing response.

These alternative interpretations are not really implausible. There is considerable evidence for directional response learning in infancy (Acredolo, 1978; Bremner & Bryant, 1977; Cornell & Heth, 1979; Pick, Yonas, & Reiser, 1979). Furthermore, there is a good reason why infants might associate a sound with the place of a synchronized object. Adults who viewed these events under the conditions of the familiarization episodes report experiencing a "ventriloquism effect": they report the sound coming from the direction of the synchronized object (Spelke, 1979a). If infants experience a similar effect, then they might learn during familiarization to relate two characteristics of the sound itself: its quality and its location.

Experiments 3 and 4 were undertaken to determine if infants learned about relations between sounds and visible objects. Experiment 3 investigated whether learning about sound–object relationships, rather than about sound-place or sound-response relationships, guided looking in the search test. Experiment 3 was identical to Experiment 1, except the left–right positions of the two visible objects were reversed between the familiarization periods and the search test. If infants learned to relate sounds to objects, they should search for the formerly synchronized object—turning in a new direction and to a new place.

Method

The 16 participants were aged 3 months, 21 days, to 4 months, 20 days (mean 4 months, 7 days). Three additional infants failed to complete the experiment due to fussiness. Infants were healthy and full-term, and they lived in or near Philadelphia.

The experimental method was identical to Experiment 1, except in one respect. After the second familiarization period and before the search test, the lateral positions of the two filmed objects were reversed. This was accomplished by mounting each projector on a moveable circular platform. The platforms could be rotated to project each film on either screen.

Two observers recorded the looking pattern of every infant. Agreement during the preference episode ranged from 70.0 to 98.6% and averaged 85.6%. During the search episode, it ranged from 74.4 to 93.3% and averaged 83.3%. For the principal analyses, an average of 8.1 search trials (57% of those administered) were scorable for each infant.

Results

Familiarization period. Looking times are given in Table 5. Infants looked longer to the synchronized object during the first session and looked equally to both objects during the second session. Twelve infants preferred the synchronized object during the first session, 7 during the second session, and 11 during both sessions combined. Only the first session majority is marginally significant, $p < .10$. There was no preference for either side or animal.

TABLE 5
VISUAL PREFERENCE FOR AURALLY SYNCHRONIZED EVENTS: EXPERIMENT 3

	Looking time (sec), synchronized event	Looking time (sec), nonsynchronized event	$t(15)$
Session 1	52.81	31.61	2.06*
Session 2	39.86	42.33	−0.25
Mean	46.33	36.97	1.88*

* $p < .10$, two-tailed.

Search test. The results of the search episode are given in Table 6. Infants tended to respond to the sound-appropriate object on more trials according to the preliminary analysis. Ten infants showed this pattern, whereas three showed the opposite tendency, $p < .05$. On the principal analysis, infants tended to look first and eventually to the object that had been synchronized with each sound. They also looked a bit faster and longer to that object, although these differences were smaller. Appropriate search was exhibited by 8 of 10 infants on the first look measure ($p < .06$), by 10 of 12 infants on the eventual look measure ($p < .02$), by 10 of 15 infants on the latency measure (NS), and by 9 of 16 infants on the duration measure (NS). There was no tendency, on any measure, to look in the former direction from which a sound-synchronized object had appeared. There was also no tendency to search preferentially for one animal or to one side.

To examine whether changing the objects' locations affected infants' search, the results of Experiments 1 and 3 were compared. Four 2 × 2 mixed factor analyses of variance (ANOVAs) were conducted: one for each search measure. Location (constant in Experiment 1 vs reversed in Experiment 3) was the between-subjects factor, and Object (formerly synchronized with the sound vs formerly nonsynchronized) was the within-subjects factor. On the first look measure, there was a significant effect of Object, $F(1, 30) = 9.88, p < .01$, no effect of Location, $F(1, 30) = <1$, and no Location by Object interaction, $F(1, 30) < 1$. The eventual look measure similarly revealed an effect of Object, $F(1, 30) = 11.36, p < .01$, and no other effects, both F's$(1, 30) < 1$. Infants in both Experiment 1 and Experiment 3 looked first and eventually more often to the object that had been synchronized with each sound. Changing the locations of the objects did not affect this tendency. Seventeen infants looked first more often to the appropriate object and three showed the opposite tendency, $p < .01$. On the eventual look measure, 18 infants showed the predicted pattern and 5 showed the opposite pattern, $p < .001$.

TABLE 6
VISUAL SEARCH FOR SOUND-APPROPRIATE OBJECTS: EXPERIMENT 3

Search measure	Appropriate object (new direction)	Inappropriate object (old direction)	$t(15)$
Preliminary measure (No. trials)	8.19	5.94	1.92*
First look (No. trials)	4.31	3.62	1.77*
Eventual look (No. trials)	7.88	7.12	2.78**
Latency (sec)	1.28	1.51	1.20
Duration (sec)	1.88	1.71	0.47

* $p < .05$, one-tailed.
** $p < .01$, one-tailed.

Results of the latency and duration analysis were somewhat different. Both revealed a main effect of Location: When the object positions were reversed, infants looked at both the appropriate and inappropriate objects with shorter latencies, $F(1, 30) = 26.46, p < .01$, and for longer durations, $F(1, 30) = 17.95, p < .01$. There was little effect of the learned auditory–visual relationships on these measures. There was a marginally significant main effect of Object on the latency measure, $F(1, 30) = 3.92, p < .10$, and no main effect of Object on the duration measure, $F(1, 30) < 1$. Above all, there was no Location by Object interaction on either measure, both F's$(1, 30) < 1$. Twenty of thirty-one infants looked to the sound appropriate objects with shorter latencies than to the inappropriate objects, $p < .025$. Sixteen of thirty-two infants looked to the appropriate objects for a longer duration, NS.

Discussion

When infants were presented with a sound, they searched reliably for the object that had moved in synchrony with it. They did this whether the object appeared in its former location or in a new location. These findings indicate that infants learned about the relationships between sounds and visible objects. Experiments 1 and 3 provide no evidence for place-learning or response-learning. Infants may learn to relate sound to places or responses, but they fail to display this learning in the search tests. The present experiments may have been especially sensitive tests of sound–object learning, and insensitive tests of place- or response-learning, because the moving objects were continuously visible to an infant during the test. Evidence for learning about places or responses might conceivably have been obtained if the visual displays had been removed from view at the start of each search trial. In any case, the experiment reveals clearly that infants learn to relate a sound to the visible object with which it has been synchronized.

EXPERIMENT 4

Experiment 4 attempted to distinguish between sound–place, sound–response, and sound–object learning as explanations for infants' performance in the transfer test of Experiment 2. Like its immediate predecessor, Experiment 4 tested infants' learning in a procedure in which the lateral positions of the two sounding objects were reversed.

Method

Sixteen infants, aged 3 months, 22 days to 4 months, 19 days (mean 4 months, 5 days) participated in this experiment. Seven additional infants failed to complete the experiment due to crying. All infants were healthy, full-term, and living in the Philadelphia area.

The method was identical to Experiment 2, except that the lateral positions of the two filmed objects were switched during the intermodal transfer test. Each object thus appeared in a new location during the two preference episodes of the transfer test. Two assistants observed each infant. Agreement during the familiarization period ranged from 64.7 to 96.6% and averaged 81.1%. Agreement during the sound presentations of the transfer test ranged from 54.8 to 100.0% and averaged 87.0%. Reliabilities during the novelty preference test ranged from 60.0 to 96.0% and averaged 85.0%.

Results

Familarization period. Table 7 presents mean looking times during the familiarization episode. Infants exhibited no reliable preference for either the synchronized or nonsynchronized object during each familiarization period. Nine infants showed a preference for the synchronized object during the first session, seven during the second session, and nine during both sessions combined, all p's $> .10$. There were preferences for neither animal nor side.

Transfer test. Looking times during the transfer test are given in Table 8. There were no consistent preferences during the sound-alone episodes of the transfer test. Eight infants preferred the side where the sound-appropriate object had been projected and seven preferred the other side, NS. During the preference tests, infants exhibited some reduction of interest in the object that had formerly been synchronized with the preceding sound, but the reduction was not significant. Ten of 16 infants looked preferentially to not reject $p > .10$. There were no animal or side preferences.

The results of Experiments 2 and 4 were compared to determine if intermodal transfer was affected by the change in object positions. Two 2 × 2 mixed-factor ANOVAs tested the effect of the reversal of the object locations on infants' looking patterns. One analysis focused on mean looking to each screen during the sound-alone episodes and the other on mean looking to each object during the preference tests. In each analysis, Object Location (constant in Experiment 2 vs reversed in Experiment 4) was the between-subjects factor and Object (formerly synchronized with the preceding sound vs formerly nonsynchronized) was the within-

TABLE 7
VISUAL PREFERENCE FOR AURALLY SYNCHRONIZED EVENTS: EXPERIMENT 4

	Looking time (sec), synchronized event	Looking time (sec), nonsynchronized event	$t(15)$
Session 1	43.07	45.51	−0.18
Session 2	42.66	32.96	0.92
Mean	42.86	39.23	0.97

TABLE 8
PREFERENTIAL LOOKING DURING THE INTERMODAL TRANSFER TEST: EXPERIMENT 4

	Auditory periods			Visual periods		
	Looking time (sec), direction of specified object	Looking time (sec), direction of nonspecified object	$t(15)$	Looking time (sec), "old" object	Looking time (sec), "new" object	$t(15)$
Session 1	9.20	6.89	0.54	8.53	14.51	1.74*
Session 2	5.00	1.75	1.33	8.11	12.13	1.13
Mean	7.10	4.32	0.86	8.32	13.32	1.61*

* $p < .10$, one-tailed.

subjects factor. The sound-alone analysis revealed no significant effects, all F's$(1, 30) < 1$. The preference test analysis revealed a significant effect of Object, $F(1, 30) = 8.81$, $p < .01$. There was no effect of Location and no Location × Object interaction, both F's $(1, 30) < 1$. During the sound-alone episodes, only 16 of 32 infants preferred the side where the sound-related object had been, $p > .10$. During the preference test, 21 of 32 infants looked longer to the object whose sound had not been played, $p < .02$.

Discussion

Experiment 4, like Experiment 3, provided no evidence that infants learn to relate a sound to a place or a response. It suggested, in contrast, that infants learn about the relations between sound and visible objects. During the intermodal transfer tests, familiarization with a sound produced a decline of interest in a formerly synchronized object, and did so regardless of whether the location of the object was old or new. The finding that infants learned to relate sounds with objects was supported by statistical comparisons of Experiments 2 and 4. Infants in both studies tended to look to the object that was not specified by the preceding sound, and this tendency was unaffected by the reversal of object locations. The evidence for auditory-to-visual transfer in this study by itself, however, was equivocal. When Experiment 4 was analyzed by itself, the preference for the novel object was not statistically reliable, as it had been in Experiment 2.

During the familiarization period, infants showed no consistent preference between the synchronized and nonsynchronized object. This finding is consistent with the results of many of the experiments that have used this method.

GENERAL DISCUSSION

These experiments support four conclusions. First, 4-month-old infants can learn rapidly about a relationship between the audible and visible appearance of a moving object. Learning occurred in one laboratory session, during familiarization periods lasting under 2 minutes. This finding corroborates those of Lyons-Ruth (1977) and Lawson (1980). Second, learning about auditory–visual relationships can occur when infants view an object moving and sounding in temporal synchrony. The object and sound need not be presented from the same spatial direction, and the synchronized object need not be the only object visible at the time the sound occurs. Further studies are needed to determine whether these other factors influence learning about sound–object relationships. Lawson's (1980) research suggests that learning is sometimes affected by the spatial relationship of a sound and object.

Third, learning about an auditory–visual relationship transfers to situations in which the objects appear in new locations. This transfer indicates infants do not learn only to relate each sound to a place or to a directional response. Again, further studies could investigate whether sound–place or sound–object learning ever occurs. Fourth, infants are able to use what they learn about sound–object relationships in two of the ways adults do. Knowledge about auditory–visual relationships guides infants' looking for an object they hear. Such knowledge also allows infants to detect an object with definite visible characteristics by listening alone.

These experiments provide further evidence that infants are capable of perceiving and learning about bimodally specified events. They invite us to consider the nature of the learning process itself and the role of learning in intermodal development. Demonstrations of intersensory coordination in young infants now abound (for reviews, see Butterworth, 1980; Mendelson, 1980; Spelke, 1980). But if infants can learn about intermodal relationships in minutes, most of these demonstrations provide questionable evidence for innateness. Do vision and audition provide experiences that are initially separate and rapidly become associated through a simple and general learning process? Or does an innate coordination of the senses guide the learning process itself?

Although learning clearly plays a major role in perceptual development, I do not think the present results argue for an initial separation of the senses. Rather, the infant's learning capacities themselves may depend on innate perceptual abilities. In the present experiments, infants learned to relate sounds and objects very quickly, with no clear reinforcement for doing so. It seems possible they are prepared to learn about such relationships. Infants might not learn so rapidly to relate the sound of an impact to a puff of air, or even to another kind of visible event such as a change in the illumination of a room. Rapid learning may occur precisely because the infant innately tends to relate certain optic and acoustic patterns to each other. To my knowledge, these conjectures have not been tested. If they turn out to be correct, then the infant's ability to learn rapidly about auditory–visual relationships will itself testify to the existence of innate structures.

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RECEIVED: October 29, 1979; REVISED: May 22, 1980.