Infants' Response to Temporally Based Intersensory Equivalence: The Effect of Synchronous Sounds on Visual Preferences for Moving Stimuli

DAVID J. LEWKOWICZ

N. Y.S. Institute for Basic Research in Developmental Disabilities

Four- and 8-month-old infants' responses to temporally based auditory-visual equivalence were investigated in a series of experiments. In the first experiment, infants viewed pairs of computer-generated visual stimuli that moved at different rates while a sound occurred each time one of the stimuli reversed its direction of motion at the bottom of the screen. Contrary to previous reports, infants even as old as 8 months of age did not respond to the auditory-visual correspondence. To determine if this was due to the infants' failure to detect the correspondence per se, or to the paired-preference method, an habituation-test experiment was conducted. Following habituation to a single moving visual stimulus and a sound that occurred when the visual stimulus reversed its direction of motion, the infants were given one test trial where the sound was no longer synchronized with direction reversal, and one where no sound occurred at all. Four-month-old infants exhibited only limited evidence of discrimination of the change in the temporal relationship between the visual stimulus and the sound, and no evidence of discrimination when the sound was absent. In contrast, 8-month-old infants discriminated both types of changes, indicating that their lack of response to the auditory-visual correspondence in the paired-preference experiments was not due to their inability to respond to it. To find out whether rate differences prevented the infants from responding to auditory-visual synchrony, rate differences were eliminated in a third experiment and the two stimuli were moved at the same velocity but out of phase with one another. Thus, the sound was synchronized with the direction reversal of one of the visual stimuli. Both age groups exhibited intersensory matching in that they looked longer at the stimulus whose direction reversal corresponded to the sound. This was true, however, only when the sound corresponded to the visual stimulus that began to move first.

infants intersensory equivalence audition vision

This work was supported in part by funds from the New York State Office of Mental Retardation and Developmental Disabilities and by NICHD Grant # HD 24371. I thank Marci Dabbene for her assistance in data collection and Judith Gardner and Gerald Turkewitz for their helpful comments on an earlier version of this article.

Correspondence and requests for reprints should be sent to David J. Lewkowicz, N.Y.S. Institute for Basic Research in Developmental Disabilities, 1050 Forest Hill Rd., Staten Island, NY 10314.

A great deal of the infant's perceptual experience is characterized by moving, sounding objects. Quite often the visible and audible properties of moving and sounding objects specify a single, unitary event. An obvious example of this is a bouncing ball that makes a sound each time it comes into contact with the surface it is bouncing on. The rate at which the ball is bouncing and the rate at which it produces a sound are directly correlated. Detection of this relationship depends on the ability of the observer to respond to the fact that the temporal attributes specified by the visible aspect of this event are related to the temporal attributes specified by the audible aspect of such an event. Indeed, because temporal change is ubiquitous and provides an excellent basis for integrating multimodal inputs (Lewkowicz, 1989a), a large portion of the research on the development of intersensory integration in human infants has focused on infants' ability to respond to temporal attributes of stimulation (Lewkowicz, 1991; Rose & Ruff, 1987). When considered together, the findings from these studies have indicated that by the fourth month of life and thereafter, infants exhibit a capacity for detecting the relationship between auditory and visual stimulation on the basis of rhythm (Allen, Walker, Symonds, & Marcell, 1977; Mendelson & Ferland, 1982), synchrony (Bahrick, 1983; Dodd, 1979; Kuhl & Meltzoff, 1982; Lewkowicz, 1986; Walker, 1982), and duration (Lewkowicz, 1986).

Of greatest interest from the standpoint of the work reported in this article are the studies concerned with infants' response to rate variations and synchrony. For example, Spelke (1979) and Spelke, Born, and Chu (1983) reported that 4-month-old infants prefer to look at a bouncing object whose rate of impact with a surface corresponds to the rate at which a sound is made, and that no prior experience with these specific multimodal events is necessary. Bahrick (1987) reported that infants' visual preferences for objects moving in different ways were guided by the sounds they made, and the basis for this was the synchronous relationship between the sounds and the motion of the objects. In a second series of studies, Bahrick (1988) showed that infants younger than 4 months of age needed prior experience with such multimodal events before they exhibited a preference for the visual stimulus matching the sound.

In contrast to these findings, however, other experiments have not revealed such preferences in young infants. For example, Lewkowicz (1985) tested 4-month-old infants' visual preferences with spatially static visual stimuli (i.e., flashing checkerboards) and temporally related sounds, and did not find matching based on the co-occurrence of the visual and auditory stimuli. Instead, the findings indicated that the presence of a sound whose repetition rate corresponded to one member of a pair of flashing checkerboards had the effect of producing a generalized shift in visual preferences that was not based on the specific temporal relationship (i.e., a match) between the visual and auditory stimulation. In subsequent studies aimed at replicating these findings, Moore and Gibbons (1988) found the same types of nonspecific, alized effects. Both Moore and Gibbons (1988) and Humphrey and Tees (1980) also reported a failure to obtain auditory-visual matching of rate at 4 months of age with spatially static visual stimuli. As a result, questions regarding the generality of intersensory abilities in early infancy can legitimately be raised.

The reasons for the differences in findings are not as yet clear. The major difference between the Spelke and Bahrick experiments and those failing to obtain matching is that visual stimuli that moved in space were presented in those experiments reporting auditory-visual matching, whereas spatially static stimuli were presented in those experiments finding no evidence of matching. This suggests that motion in the visual modality may provide a basis for the auditory-visual matches. Yet, Lewkowicz's (1986) finding of successful auditory-visual matching based on duration and/or synchrony in 6-month-olds who were tested with spatially static displays, and Lewkowicz's (1989b) and Humphrey and Tee's (1980) findings of successful auditory-visual matching of rate with spatially static displays by 10 months of age, suggests that motion may not be essential. It might, however, serve to make auditory-visual matching easier and thereby appear earlier in development.

Because of the inconsistent findings in this area, it was felt that it was important to conduct further studies of infants' responsiveness to temporally related auditory-visual events. Although the studies reported in this article were not conceived as a direct attempt to replicate some of the previous findings, methods similar to those employed in prior work were used. Visual stimuli moving in various ways and sounds that were related to the motion of those stimuli were presented to determine whether infants would detect the auditory-visual correspondence.

The experiments here went beyond prior studies by: (a) investigating infants' intersensory response to rate by examining the separate contribution of repetition and velocity to such responsiveness; (b) extending the examination of infants' intersensory responsiveness to rate variations produced by kinetic displays to ages beyond 4 months; (c) extending the range of temporal variations beyond those studied in prior investigations to assess the generality of the previously reported findings; and (d) testing infants' detection of intersensory correspondence in both a choice task and a discrimination task. The choice task was the standard paired-preference intersensory matching method that was used in all previous work in this area. The discrimination task consisted of habituating infants with a unified auditory-visual compound stimulus and then testing their response to the same compound when the temporal relationship between the components was disrupted.

EXPERIMENT 1

In this experiment, infants were shown pairs of visual stimuli where the members of each pair moved at different rates. While the infants viewed these visual stimuli, an auditory stimulus was sounded each time one of the visual stimuli reversed its direction of motion when it reached the bottom of the display. The impression created by this display was that of two balls bouncing at different rates with one of the balls producing a sound each time it hit bottom.

To permit precise temporal control over the stimuli, both the visual and auditory stimuli were generated and controlled by a computer. The visual stimuli were two-dimensional, graphic images and the auditory stimulus was a spectrally complex sound. These types of stimuli were specifically chosen because they offer two very important advantages. First, they permit precise control over the temporal parameters of the stimuli. Second, because they are generally unfamiliar to infants, these types of stimuli minimize the possibility that differential experience at different ages might influence responsiveness. In order to examine responsiveness over a broader range of stimulus velocities, the visual stimuli were moved at three, rather than two, rates of stimulus motion, and responsiveness to all possible pairings of the three rates was investigated.

Method

Subjects. Twenty-four 4-month-old infants (14 males, 10 females), with a mean age of 19 weeks and 2 days (SD = 6 days), were tested. Seven additional infants did not complete testing because of fussing or crying (n = 4), sleepiness (n = 2), and inattentiveness (n = 1). Twenty-four S-month-old infants (9 males, 15 females), with a mean age of 35 weeks and 3 days *(SD* = 5.6 days), were also tested. Two additional infants did not complete testing because of inattentiveness. The infants in this experiment, as well as the infants in all the subsequent experiments, were full-term at birth (i.e., > 2500 gms, and > 37 weeks gestational age at birth), with uncomplicated perinatal histories, and in good health at the time of testing.

Apparatus and Stimuli. During testing the infant sat 18 inches (45.72 cm) in front of a video monitor 25 diagonal inches (63.5 cm) in size. To block the infant's view of the laboratory, the monitor was enclosed with a black curtain that extended out on each side past where the infant was sitting. The visual stimuli were computer-generated sprite graphics produced by a Supersprite video display board running inside an Apple IIe microcomputer. During each trial a pair of identical stimuli was displayed. These stimuli were circular two-dimensional green images that subtended 3°48" of visual angle and were located on either side of the screen, 15 inches (38.1 cm) apart. The auditory stimulus was generated by the sound chip on the Supersprite board. It was a spectrally complex sound whose envelope descended in time. Its overall duration was 271 ms and it measured 63 dB (20 *u*N/m2, A) at the infant's ear. A spectrum analysis indicated that the sound had a fundamental frequency of 62.5 Hz and several harmonic peaks. The sound was presented through two speakers, one on each side of the monitor. A baffle, oriented at a 45° angle with respect to the side of the monitor and located behind each speaker, helped project the sound towards the infant.

Procedure. Each infant was tested individually in a dimly illuminated room while sitting on the parent's lap. The ambient sound pressure level in the room, as measured at the infant's ear, was 56 dB (20 uN/m2, A). Prior to testing, the parent was informed that we were interested in seeing the baby's reactions to moving and sounding objects; otherwise, the parent was naive about the experiment. The parent was asked to sit as still as possible and not talk or interact with the baby in any way during the testing session.

Each trial began with the display of a multicolored image of a schematic face in the center of the screen. The purpose of this was to get the infant to look at the center of the screen before the beginning of each trial. As soon as the infant was judged to be looking in the center, the trial was initiated. The trial began with both stimuli appearing simultaneously at the same horizontal level at the top of the screen. As soon as they appeared, the stimuli began to move down. When they reached the bottom of the screen they reversed direction and began to move up until they reached their starting point. The distance that both stimuli travelled was identical (31.5 cm). This cycle of downward followed by upward motion continued for the duration of the test trial. Because the two stimuli on a given trial moved at different rates, the two members of the pair reached the bottom of the screen at different times. Each time one member of the pair reversed its direction of motion at the bottom of the screen the auditory stimulus was sounded. The onset of the sound was set to coincide with the precise point at which the corresponding stimulus reversed its direction of motion.

Each stimulus, regardless of the specific rate at which it moved, spent half its time moving in the downward direction and half its time moving in the upward direction. This meant that, at a given rate of motion, the velocity of the stimulus was the same in both the downward and upward directions.

Each infant was administered a total of 12 trials, and the duration of each test trial was 30 s. During each trial, two stimuli moving at one of three different rates were presented. The three rates of motion were .22, .42, and .98 Hz. These were the result of moving the stimulus at 16°35" (slow), 30°48" (intermediate), or 72°13" (fast) of visual angle/s, respectively. The three pairs resulting from all possible combinations of the three different rates of motion were presented. Each of these three pairs was presented during four separate trials. Two of these four trials occurred consecutively, and during the second of these two trials, the stimuli were laterally reversed to control for lateral preferences. On each of these two trials, a sound whose occurrence was synchronized with the reversal in the direction of motion of one member of the pair was presented. During the other two trials involving presentation of the same pair, the sound was synchronized with the reversal in the direction of the other member of the pair. To control for order effects, each set of the two test trials involving presentation of the sound that corresponded to the same member of the pair was treated as a block. Six orders of the six blocks of trials were generated. The orders were constructed with the restriction that each block appear once at each ordinal position. Four infants were randomly assigned to each of these six orders.

In this study, the color of both stimuli on a given trial was either green, blue, or orange for each of the two trials involving a unique visual-stimulus-pair-sound combination. The different colors were used because it was believed that color changes might be needed to maintain the infants' attention. Different random orders of the three colors were used across the six pair orders.

The entire testing session was videotaped with a camera positioned on top of the monitor and visual fixations were scored off-line from the videotape by a trained observer. During scoring, the videotape was played in silence, and the observer was unaware of the specific visual stimuli that the infant was seeing on each trial. Interobserver reliability was established by having two observers, who were unaware of the testing conditions, score 36 trials of 3 randomly chosen infants. A correlation of .97 was obtained when the durations of fixation per trial from one observer were correlated with the durations obtained by the other observer.

Results and Discussion

The total duration of visual fixation accorded to each member of each pair of visual stimuli was the dependent measure. Table 1 shows the mean total duration of looking for each pair for each age group.

As a first step, a separate visual rate x auditory rate analysis of variance (ANOVA) was conducted on the data from each pair. This ANOVA compared looking at each member of the pair in the presence of the sound that was synchronized with one member of the pair versus looking in the presence of the sound that was synchronized with the other member of the pair. Visual rate and auditory rate were both within-subjects variables. No significant differences were found at either age. Separate t tests at each rate of sound presentation were then used to determine whether there were any differences in looking in any of the pairs. These, like the previous analyses, showed that the 4-month-old infants did not look longer at the visual stimulus whose rate of motion corresponded to the repetition rate of the accompanying sound. The S-month-old infants looked longer at the faster member of the slow-fast pair and the slow-intermediate pair. Although the greater looking at the intermediate visual stimulus in the presence of the intermediate sound might be interpreted as intersensory matching, when this finding is considered in the

TABLE 1
Average Looking Time for Each Pair of Visual Rates in Relation to Each Sound Rate in Experiment 1

	Visual Pair		
Sound Rate	Slow-Intermediate	Slow-Fast	Intermediate-Fast
Slow			
4-month-olds	19.8(6.3)-24.7(8.0)	23.4(7.3)-22.6(7.6)	
8-month-olds	19.7(6.4)-21.9(7.5)	19.2(6.5)-24.6(5.4)*	
Intermediate			
4-month-olds	20.9(6.1)-24.3(7.2)		20.6(9.3)-24.9(8.8)
8-month-olds	19.4(3.8)-23.5(7.1)*		22.7(8.0)-21.3(8.2)
Fast			
4-month-olds		21.1(8.6)-24.1(10.6)	20.9(7.1)-22.8(8.7)
8-month-olds		23.8(8.6)-22.6(7.1)	19.4(8.1)-21.4(6.6)

Note. The tabled values represent the mean amount of total looking at the corresponding member of the pair of visual stimuli. Standard deviations appear in parentheses.

*Difference between the scores for that pair was significant at $p < .05$.

context of all the other pairs it becomes obvious that such an interpretation is unwarranted.

Although the major dependent measure in this series of experiments is the total duration of looking, prior experiments have also examined the direction, or the duration, of the first look on a given trial and have reported more first looks to the visual stimulus that was synchronized with the occurrence of the sound. Separate analyses of the frequency and the duration of first looks in this experiment did not, however, indicate that infants at either age accorded greater initial attention to the visual stimulus that was synchronized with the sound.

In sum, the results from this experiment provided no evidence to suggest that 4- or &month-old infants detected the correspondence between a repetitive sound and a visual stimulus whose change in direction of motion was synchronized with the occurrence of the sound. These results differ from the findings reported by Spelke (1979) in the first experiment in which Spelke studied 4-month-old infants' intersensory response to rate, and they are similar to the failure to find auditory-visual matching of rate in 4-month-old infants by Humphrey and Tees (1980), Lewkowicz (1985), and Moore and Gibbons (1988) with spatially static visual stimuli.

The reason for the failure to obtain auditory-visual matching in this experiment is unclear, particularly because the infants were presented with a greater range of rates than were the infants in Spelke's experiment. It is also surprising that even the 8-month-old infants did not perform the matching. It is interesting to note, however, that the greater looking at the stimulus moving at the faster rate reported by Spelke (1979) in the 4-month-old infants was not found in this experiment. When considered together with the previously cited failures to find intersensory matching, the results suggest that spatial displacement and velocity information do not facilitate detection of an auditory-visual relationship based on rate, even as late as 8 months of age.[1]

EXPERIMENT 2

The failure to exhibit a visual preference for the visual stimulus whose direction reversal was synchronized with a sound does not necessarily indicate that the infants cannot detect this form of auditory-visual correlation. It is quite possible that they may be capable of detecting the auditory-visual correlation but may simply have no preference for one object over the other regardless of its temporal relationship to the sound. If infants are capable of detecting the correlation between the occurrence of a sound and the spatial-

---

[1] The results from Experiment 1 do not rule out the possibility that spatial displacement and the accompanying velocity information facilitate intersensory responsiveness. One way in which these two variables can serve to accentuate the synchronous relationship between a moving visual stimulus and the occurrence of an acoustic event is to have the stimulus undergo a relative change in velocity at the precise point when the sound occurs. To test this possibility, a study with 24 4-month-old and 24 8-month-old infants was conducted where identical procedures and stimulus materials were used except that both visual stimuli moved down at 23”55” visual angle/s but moved up at one of three different velocities: 23”55”, 35”56”, or 54”lo” visual angle/s. Three possible pairs of these three upward velocities, counterbalanced for side, were presented. Thus, when the stimuli reached the bottom of the display, one was accelerated while the other continued to move at the same velocity, or both could be accelerated but to different degrees. By making the occurrence of the sound correspond to one member of each of these pairs it was then possible to determine whether accentuation of the auditory-visual synchrony through relative acceleration facilitates detection of the auditory-visual relationship. An adult looking at the visual display of the two moving stimuli and listening to the sound has no problem in detecting which visual stimulus corresponds to the sound. Yet, no evidence of intersensory matching was found in the infants at either age.

A second experiment was then conducted to investigate whether infants can detect intersensory correspondence when velocity is held constant, and as a result, only rate differences are present. This can be done by having two objects move at the same velocity but having one come to a rest periodically while the other continues to move. Stimuli and procedures identical to those in the previous two experiments were used, but this time, one of the visual stimuli moved continuously through space while the other stimulus paused periodically at the top of its motion trajectory. When the stimuli were moving, they did so at the same velocity. A pair of stimuli moved at one of three different velocities across different trials: 16”35”, 35”56”, and 72”13” of visual angle/s. The corresponding rates of motion for the stimulus that paused were .12, .17, and .21 Hz, respectively, whereas the corresponding rates for the stimulus that moved continuously were .22, .49, and Hz, respectively. The auditory stimulus was sounded whenever one member of the pair of stimuli reversed direction at the bottom of the display. Twenty-four infants at 4 and 8 months of age were tested. Results indicated no evidence of intersensory matching; instead, the infants showed a clear preference for the continuously moving stimulus.

temporal characteristics of a visual stimulus, it should be possible to demonstrate that they can detect the disruption of that correlation.

To examine this possibility, an infant-controlled habituation-test technique was used. First, a single visual stimulus moving at one of the three velocities used in Experiment 1 and a sound that occurred whenever the stimulus changed direction at the bottom of the screen were presented over a series of trials to each infant. As soon as the infant's response to this compound auditory-visual stimulus declined to a predetermined level, two types of test trials were administered. During one type of test trial (the asynchronous test trial), the same visual stimulus, moving at the same velocity, was presented, but this time the sound occurred when the stimulus reached the middle of its downward motion trajectory. In this way, the occurrence of the auditory stimulus was no longer synchronized with the direction reversal of the visual stimulus. It was expected that, if the infants did indeed detect the specific temporal relationship between the visual and auditory stimuli, this should be evident in a significant response recovery. During the other type of test trial (the silent test trial), the infants were again presented with the same visual stimulus except that this time the sound was not presented at all. It was expected that if the infants detected the absence of the sound, they would exhibit significant response recovery.

Method

Subjects. Twenty-four 4-month-old infants (12 males, 12 females), with a mean age of 17 weeks (SD = 4.1 days), were tested. Fifteen additional infants did not complete testing because they fussed or cried (n = 7), were inattentive (n = 3), or sleepy (n = 4), or because the parent interfered with the infant during the test (n = 1). Twenty-four 8-month-old infants (13 males, 11 females) with a mean age of 36 weeks and 4 days (SD = 4 days) were also tested. Three additional infants did not complete testing because of fussing (n = 1) and parent interference (n = 2).

Apparatus and Stimuli. The apparatus and stimuli were identical to those used in the previous experiment with the following exceptions. Instead of a pair of visual stimuli, only one stimulus was presented during each trial. The monitor was covered with an oak tag panel with a rectangular window cutout measuring 7.5 cm in width and 34 cm in length. This window was located 45" to the left of the infant. The window was displaced to the side in order to require a clear directional response on the part of the infant. In order to attract the infant's attention to the window, the schematic face was displayed in the center of the window prior to the start of each trial.

Procedure. The infant-controlled habituation procedure was used in this experiment. The infant was seated in an infant seat and when he or she looked at the face in the window the visual stimulus appeared at the top of the screen and began to move in the downward direction. During the habituation phase, a sound (the same as in Experiment 1) occurred each time the stimulus reversed its direction at the bottom of the screen. The experimenter observed the infant on a video monitor and controlled the presentation of the stimuli by watching the infants' eyes and initiating trials whenever the infant looked at the face in the window. The experimenter could not see the visual stimulus, and the auditory stimulus was masked by music that the experimenter listened to through a set of headphones throughout the test session. As long as the infant looked at the window, the stimulus continued to move up and down, with the sound occurring whenever the stimulus reached bottom. As soon as the infant looked away for more than 1 s, the stimulus disappeared, and the sound ceased. This was deemed the end of a trial.

The habituation phase lasted until the total amount of looking time in the last three habituation trials declined to less than 50% of the total amount of looking in the first three habituation trials. As soon as this criterion was met, the test phase began with the next look.

The test phase consisted of a series of seven trials. The first two trials were one type of test trial, the next three were rehabituation trials where the original stimulus was presented, and the last two were the other type of test trial. The purpose of the rehabituation trials was to reestablish habituation prior to the administration of the second set of test trials (this was indeed successful in that there was no statistical difference in looking during the last two habituation trials and the last rehabituation trial at either age). Half the infants received the asynchronous test trials first followed by the silent test trials. The other half received these test trials in the reverse order. At each age, there were three groups of 8 infants each. Each group was habituated and tested with one of the three velocities of motion and the corresponding rates of sound presentation used in Experiment 1. During the asynchronous test trials, the sound occurred 1.1 s after the stimulus began to move downward in the group tested with the slow-rate compound stimulus, 0.6 s in the group tested with the medium-rate compound stimulus, and 0.25 s in the group tested with the fast-rate compound stimulus. Each of the values was chosen to correspond to the halfway point in the downward motion of the visual stimulus.

Data Analysis. A preliminary inspection of the data revealed that they were positively skewed. As a result, a log transformation was applied to the data and all subsequent analyses were based on the log scores. A single score for each of the two types of test trials was derived by computing the average amount of visual fixation during each of the two trials of a given type of test trial. A single habituation score was also derived by computing the average amount of looking during the last two habituation trials. The habituation score, and the score for the different types of test trials, were then used in all the analyses.

TABLE 2
Duration of Looking During the Habituation and Test Trials in Experiment 2

	Type of Trial		
Test Trial Order	Habituation M (SD)	Asynchronous M (SD)	Silent M (SD)
4-month-olds			
A/S[a]	5.07 (3.2)	7.95 (4.0)*	6.94 (4.1)
S/A	7.63 (5.1)	6.97 (4.7)	11.61 (10.4)
	6.35 (4.4)	7.46 (4.3)	9.28 (8.09)
8-month-olds			
A/S[a]	6.35 (3.5)	8.49 (7.2)	8.04 (4.05)
S/A	4.91 (1.9)	7.48 (3.9)	6.85 (1.8)
	5.63 (2.9)	7.98 (5.7)*	7.45 (3.1)*

[a]A = Asynchronous Sound Test trial; S = Silent Test trial
*Significant recovery in this particular condition.

Results and Discussion

To find out whether the specific rate of the compound stimulus, the order of the test trials, or age had an effect on responsiveness, these three between-subjects variables were entered into a four-way ANOVA with trial type (i.e., habituation and test) as the within-subjects variable. For the asynchronous test trial, there was an order × age × trial type interaction, $F(1, 36) = 4.80$, $p < .05$. There were no significant effects for the silent test trial. To determine the source of the significant three-way interaction for the asynchronous test trial, the data were analyzed separately at each age. Although no significant effects were found for the silent test trial, the data for this test trial were also analyzed separately. This was done because examination of the means and standard deviations (see Table 2) for the habituation score and for the silent test trial suggests that a significant recovery of response occurred at the older age, but that it did not occur at the younger age due to considerably greater variability at the younger age.

4-Month-Old Infants

Table 2 shows the results separately for each order of test stimulus presentation. A compound stimulus rate × test trial order × trial type ANOVA indicated that there was a trial type by order interaction, $F(1,18) = 7.46$, $p < .025$ in the asynchronous test trial. For the silent test trial, there were no significant interactions.

To determine whether a significant recovery in responsiveness occurred on each of the two test trials, the habituation score was compared with the score in each of the two types of test trials. Because the trial type by order interaction was significant for the asynchronous test trial, the data from each of the two groups receiving the different orders of the test stimuli were analyzed separately. Results indicated that the group of infants for whom the asynchronous test trial was administered first exhibited significant recovery of responsiveness, $F(1, 11) = 11.26$, $p < .01$. In contrast, the group of infants for whom the asynchronous test trial was second did not exhibit response recovery. Because test trial order did not have a differential effect for the silent test trial, the data for the two groups were collapsed. A comparison of the infants' response in the silent test trial with their habituation score indicated that there was no significant recovery of response.

The use of a subject-determined criterion of habituation introduced the possibility that regression to the mean accounted for the observed recovery of response in the test trials. To check for this possibility, a control study was carried out with a new group of 24 4-month-old infants. The identical procedure and stimuli were used, except for one minor difference. Instead of moving the visual stimuli at one of the three velocities used in this experiment, the visual stimuli were moved at one of two velocities. As a result, half of the 24 infants were habituated to a visual stimulus that moved at 26.6° of visual angle/s, and half were habituated to a visual stimulus that moved at 60.3° of visual angle/s. The corresponding rates of sound presentation were .325 Hz at the slower velocity and .73 Hz at the faster velocity. Once the infants reached the 50% habituation criterion, testing continued for an additional two trials during which the same compound stimulus was presented. These two additional lag trials were intended to determine whether looking would spontaneously recover to precriterion levels, or whether it would remain at criterion levels. The mean duration of visual fixation in the last two habituation trials during which criterion was met was compared with the mean duration of fixation in the two lag trials. A two-way ANOVA with compound stimulus rate as the between-subjects variable and trial type as the within-subjects variable indicated that there was a significant main effect of stimulus rate, $F(1, 22) = 8.45$, $p < .01$, which meant that those infants habituated to the faster compound stimulus looked longer than did those infants who were habituated to the slower stimulus. There were, however, no significant trials or trials by stimulus rate effects, indicating that there was no spontaneous recovery of looking and, therefore, that regression to the mean did not occur.

8-Month-Old Infants

The results for the 8-month-old infants can also be seen in Table 2. For the asynchronous test trial, the three-way ANOVA indicated that, although the overall level of response varied as a function of the rate at which the compound stimulus was presented during habituation, $F(2, 18) = 4.68$, $p < .05$. there were no significant interactions. There was a significant overall trials effect, $F(1, 18) = 4.95$, $p < .05$, indicating that the infants discriminated the change in the temporal relationship between the auditory and visual components.

For the silent test trial, the three-way ANOVA indicated that there was a highly significant trials main effect, $F(1, 18) = 21.27$, $p < .01$, indicating that the infants also detected the absence of the sound. In addition, there was a significant rate group by trials interaction for the silent trial, $F(1, 18) = 7.49$, $p <$ 01. This was due to a difference in the magnitude of response recovery in the three groups. Despite this difference, however, the response on the test trials was higher than the response in the habituation trials for each group.

To determine whether regression to the mean might have contributed to the recovery of response observed in the current experiment, the same control study described for the 4-month-old infants was also carried out with a new group of 24 &month-old infants. Analyses comparing the data from the criterion trials and those from the lag trials once again indicated no significant effects, thus ruling out the possibility that regression to the mean accounted for the results.

In sum, the results from this study indicate that the 4-month-old infants did not respond to the difference between the moving stimulus that had a sound associated with it and the same stimulus that no longer had the sound associated with it. The results from the asynchronous test trial indicate that under some conditions 4-month-olds did respond to the change in the temporal relationship between a moving visual stimulus and an accompanying sound. This response, however, appeared to be dependent on whether a different event occurred between the learning and testing phases. This finding is interesting in light of findings from more recent experiments conducted in our laboratory involving changes in synchrony (Lewkowicz, in press). In those studies, 4-month-old infants were first habituated with the same auditory-visual compounds that were used in the current experiments. During the test phase, however, the rate at which one of the components was presented was changed. This meant that the synchronous relationship of the two components was also disrupted because the sound no longer occurred at the same time as the visual stimulus changed its direction of motion. In contrast to the findings from this experiment, results indicated that the combined change in synchrony and rate was highly discriminable as evidenced by a marked recovery of response to these changes. Therefore, it appears that it is more difficult for 4-month-old infants to discriminate changes in synchrony when these merely involve a temporal displacement of the auditory and visual events vis-a-vis one another than when such temporal displacements are accompanied by rate changes.

In contrast to the 4-month-old infants, the &month-old infants exhibited clear evidence of discrimination of both the temporal displacement of the auditory and visual events, as well as the absence of the auditory stimulus. A comparison of the results from the two age groups suggests that there are important developmental changes in infants' ability to learn about auditory-visual relationships and in their ability to detect changes in those relationships. Although the current data cannot speak to the issue of discrimination thresholds, one possible reason for the 4-month-olds' limited capacity to respond to the change in the asynchronous condition may have been that the interval separating the occurrence of the sound and the direction reversal of the visual stimulus was below discrimination threshold.

The data from the 4-month-olds in this experiment also suggest that the failure of the 4-month-olds in Experiment 1 to exhibit a preference for the stimulus whose rate of motion corresponded to the repetition rate of the sound may have been partly due to their failure to respond to the auditory-visual relationship. At the same time, however, even when infants did respond to the auditory-visual relationship, as was the case for the 8-month-olds, they still did not exhibit intersensory matching. Thus, it appears that a positive response to a change in the auditory-visual relationship in the discrimination task need not necessarily be reflected in the infants' behavior in a paired-preference task. The failure to match in the preference studies may be related to different kinds of information-processing demands imposed by the visual preference technique. In the paired-preference task, the infant must choose to attend to one of two competing visual stimuli and base his or her choice on the relationship of each stimulus to the concurrently presented auditory stimulus. Making such a choice may be difficult, particularly when the two members of a pair differ on more than one dimension (i.e., rate and synchrony with the auditory stimulus).

One interesting difference in the infants' response during the silent test trial was the fact that the older infants discriminated the omission of the sound, whereas the younger ones did not. This missing stimulus effect (MSE) was first described by Sokolov (1963) in work on adults' orienting responses. Sokolov reported that the omission of a stimulus was just as effective in eliciting orienting as was the introduction of a novel stimulus. The present data indicate that infants as young as 8 months of age also exhibit this form of the MSE.

EXPERIMENT 3

The purpose of this experiment was to determine directly whether the presence of more than one dimension of stimulation might play a role in infants' response to intersensory correspondence. Under some circumstances, infants' response to auditory-visual compounds can be adversely affected by the availability of more than a single discriminative dimension (Lewkowicz, 1988a, 1988b). In Experiment there were two separate discriminative dimensions that could be used for differential responsiveness. One was a difference in the rate at which the two visual stimuli moved and the difference in the rate at which the auditory stimulus was sounded depending upon which visual stimulus it was synchronized with. The other was synchrony, which was determined by the spatio-temporal relationship between a given member of the pair of visual stimuli and the occurrence of the sound. One reason for the infants' failure to make intersensory matches in Experiment 1 may be that the rate difference overshadowed the synchronous relationship of the sound to one member of the pair of visual stimuli and, as a result, the infants were unable to respond to the acoustically specified stimulus. The specific purpose of this experiment was to determine whether the elimination of the rate difference would make it possible for the infants to respond to the auditory-visual relationship.

The infants in this study were, therefore, presented with two moving visual stimuli that moved at the same velocity but out of phase with one another. As in the prior experiments, the sound was synchronized with the direction reversal of one of the visual stimuli. The design of this experiment was similar to the design of Experiment 3 in Spelke (1979) and to its replication by Spelke et al. (1983). In Spelke's experiments, 4-month-old infants' responses to a pair of stimuli moving at the same velocity but out of phase with one another were studied. In both experiments, it was found that the infants preferred to look at the acoustically specified object. Unfortunately, the absolute velocity at which such an effect might operate was not studied systematically, and as a result, it is not possible to determine what limits the actual velocity of motion might impose upon intersensory matching. This makes it difficult to make broad generalizations regarding detection of auditory-visual synchrony based on Spelke's data. In addition, when two objects are moved at equal velocities, one object has to begin moving first. This might influence what stimulus an infant ultimately looks at because the leading stimulus might "prime" the infant to look at that stimulus by directing his or her attention to it first. This possibility was not examined by Spelke. Therefore, in this experiment, response to auditory-visual correspondence was investigated over three different velocities to assess the role that absolute differences in velocity play in intersensory matching. In addition, the effect of having the sound synchronized with either the leading or the lagging stimulus was investigated to determine whether the temporal precedence of one visual stimulus over the other influenced the infants' intersensory response.

Method

Subjects. Twenty-four 4-month-old infants (9 males, 15 females) with a mean age of 20 weeks and 2 days (SD = 4 days) were tested. Fourteen additional 4-month-olds did not complete testing because of fussing or crying (n = 4), inattentiveness (n = 5), sleepiness (n = 4), and distractions (n = 1). Twenty-four &month-old infants (10 males, 14 females) with a mean age of 36 weeks and 1 day (SD = 4 days) were also tested. An additional six 8-month-olds did not complete testing due to inattentiveness.

Apparatus and Stimuli. The apparatus and stimuli were identical to those used in Experiment 1 except that both stimuli were green throughout the test session.

Procedure. The testing procedure was identical to the one used in Experiment 1. In contrast to Experiment 1, however, the members of a given pair of visual stimuli moved at the same velocity in this experiment. Across trials, the following three different velocities were employed: 23°55” (slow), 35°56” (intermediate), or 54°10” (fast) of visual angle/s. The corresponding rates were: .32, .49, and .73 Hz, respectively. It should be noted that these rates differ from those used in Experiment 1. The primary reason for choosing these rates was to present a more restricted range of rates to the infants in the current experiment. Each trial began with the appearance of the leading stimulus. Shortly after the leading stimulus began to move downward, the lagging stimulus appeared and began to move. The interval separating the appearance of the leading and lagging stimulus was 570 ms for the stimuli moving at the slow velocity, 380 ms for the stimuli moving at the intermediate velocity, and 250 ms for the stimuli moving at the fast velocity. Because both stimuli moved at the same velocity, their phase relationship remained constant throughout each trial.

Two blocks of six trials each were administered to each infant. In one block of trials, the occurrence of the sound was synchronized with the direction reversal of the leading visual stimulus. In the other block of trials, the occurrence of the sound was synchronized with the direction reversal of the lagging visual stimulus. The order of the two blocks was counterbalanced across the infants, resulting in two groups of 12 infants at each age.

Within each block, each type of trial (i.e., slow, intermediate, or fast) was presented twice, once with the leading stimulus on the left and the lagging stimulus on the right and once in the reversed-pair configuration. The resulting six trials were then arranged in six possible orders such that each type of trial appeared equally often at each ordinal position. An equal number of infants was randomly assigned to each order.

Results

There were no systematic effects of pair configuration, so the data from the two trials involving the lateral reversal of each pair were combined. First, ANOVAs, with age and block order as between-subjects variables and stimulus (leading vs. lagging) and sound condition (whether the sound corresponded to the leading or lagging visual stimulus) as the within-subjects variables, were conducted on the data from each velocity condition separately. These analyses indicated that for the slow-velocity condition there was an age x block x stimulus x sound condition interaction, $F(1, 44) = 11.18$, $p < .01$. For the medium-velocity condition, there was a significant age x stimulus x sound condition interaction, $F(1, 44) = 4.38$, $p < .05$. There were no significant interactions involving age for the fast-velocity condition. Given that age entered into significant interactions for the two lower velocity conditions, separate analyses were conducted for each age group.

To support the conclusion that the infants responded to the auditory-visual correspondence, they would be expected to exhibit longer visual fixation of the visual stimulus whose change in direction of motion was synchronized with the occurrence of the sound.

4-Month-Old Infants

To determine if looking was differentially affected by whether the sound was associated with the direction reversal of the leading or the lagging visual stimulus, a three-way ANOVA with stimulus and sound condition as the within-subjects variables, and block order as the between-subjects variable was carried out separately for each velocity condition.

Slow-Velocity Condition. For the slow-velocity condition, there was a significant stimulus x sound condition x block order interaction, $F(1,22) = 6.07$, $p < .05$. To determine the source of this interaction, separate two-way ANOVAs were conducted on the data from those trials when the sound corresponded to the direction reversal of the leading stimulus and those when the sound corresponded to the direction reversal of the lagging stimulus. As can be seen in Figure 1, for those trials where the sound corresponded to the

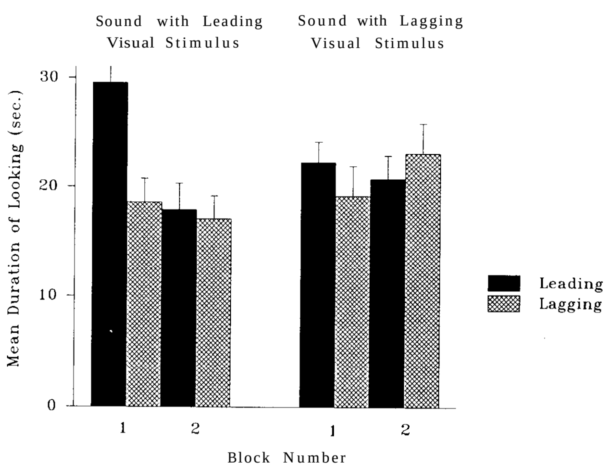

Figure 1. Mean duration of looking at the two visual stimuli as a function of which visual stimulus the sound was synchronized with and as a function of trial block. The data depicted are for the velocity condition in the 4-month-old infants.

leading stimulus, block order exerted a major effect, $F(1, 22) = 10.37$, $p < .01$; the overall level of looking was greater in the first block of trials than in the second block of trials. There was also a significant block order by stimulus interaction, $F(1, 22) = 5.30$, $p < .05$, that was due to significantly greater looking at the sounding-leading stimulus than at the silent-lagging stimulus in those infants who received these trials in the first block, $F(1, 11) = 15.61$, $p < .005$, and no difference in looking in those infants who received these trials in the second block. As can be seen in Figure 1, the mean duration of looking at the lagging-silent stimulus was similar across the two blocks of trials. Thus, the failure to fixate the stimuli differentially in the second block of trials was due to reduced looking at the leading-sounding stimulus across the two blocks, $F(1,22) = 15.09$, $p < .01$. Analyses of the trials where the sound was associated with the lagging stimulus yielded no significant effects.

Finally, separate analyses were done to determine whether looking at each type of stimulus (leading, lagging), respectively, differed depending upon whether the sound was synchronized with its direction reversal or not. This analysis indicated that in the first block of trials looking was greater when the sound was synchronized with the direction reversal of the leading stimulus than when it was not, $t(11) = 2.62$, $p < .05$. This was not the case in the second block of trials. No differential effects were found for the lagging stimulus.

Medium-Velocity Condition In the medium-velocity condition, the stimulus x sound condition interaction was also significant, $F(1, 22) = 19.54$, $p < .001$, indicating that response to the two visual stimuli differed depending on

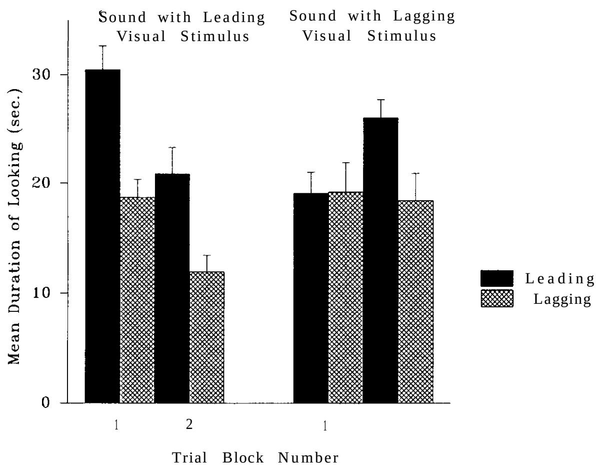

Figure 2. Mean duration of looking at the two visual stimuli as a function of which visual stimulus the sound was synchronized with and as a function of trial block. The data depicted are for the medium-velocity condition in the 4-month-old infants.

which stimulus the sound was synchronized with. Analyses of the data from the trials where the sound was associated with the leading stimulus indicated that, once again, there was greater overall looking in the first block of trials than in the second block, $F(1,22) = 25.46$, $p < .001$ (Figure 2). Figure 2 also shows that the infants looked longer at the leading-sounding stimulus than at the lagging-silent stimulus in each block of trials, and this was borne out by an overall stimulus effect, $F(1, 22) = 20.38$, $p < .001$. Separate analyses of the data from each block indicated that the infants looked longer at the leading-sounding stimulus both in the first, $F(1, 11) = 11.28$, $p < .01$, and in the second, $F(1, 11) = 9.11$, $p < .05$, block of trials. Analyses of the data from the trials where the sound was associated with the lagging stimulus indicated that there were no significant effects.

In the first block of trials, the infants looked longer at the leading stimulus when its direction reversal was accompanied by the sound than when it was not, $t(11) = 4.50$, $p < .01$. This was not the case in the second block of trials. The infants also looked longer at the lagging stimulus when it was accompanied by the sound than when it was not, but this was only the case in the second block of trials, $t(11) = 2.45$, $p < .05$.

Fast-Velocity Condition. Analyses of the data from the fast-velocity condition provided no evidence of intersensory matching (see Figure 3). The only significant finding was that the overall amount of looking was greater in the first than in the second block of trials, $F(1,22) = 11.79$, $p < .005$, replicating the effect in the two lower velocity conditions. The only other effect was that

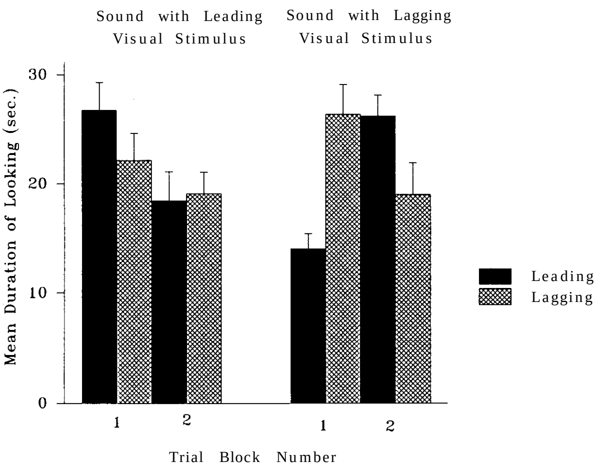

Figure 3. Mean duration of looking at the two visual stimuli as a function of which visual stimulus the sound was synchronized with and as a function of trial block. The data depicted are for the velocity condition in the 4-month-old infants.

there was a significant stimulus x block order interaction, $F(1,22) = 11.81$, $p < .01$. This was due to significantly greater looking at the lagging-sounding stimulus when the pair was presented in the first block of trials, $F(1, 11) = 12.12$, $p < .01$, but no significant difference in looking when the pair was presented in the second block of trials. Interestingly enough, however, looking at the leading stimulus when its direction reversal was accompanied by the sound than when it was not accompanied by it was greater in the first block of trials, $t(11) = 4.86$, $p < .01$. In the second block of trials, however, this preference reversed itself in that the infants preferred to look longer at the leading stimulus when its direction reversal was not associated with the sound, $t(11) = 3.10$, $p < .05$. Analyses of the frequency and duration of first looks did not indicate any systematic effects that would suggest intersensory matching.

8-Month-Old Infants

In general, the findings from the 8-month-old infants paralleled those from the 4-month-olds.

Slow-Velocity Condition The three-way ANOVA for the slow-velocity condition indicated that there was a significant stimulus x sound condition interaction, $F(1,22) = 4.76$, $p < .05$, as well as a significant stimulus x sound condition x block order interaction, $F(1, 22) = 5.12$, $p < .05$. Separate analyses of the data from each of the two sound conditions indicated that in the trials where the sound was associated with the leading stimulus, there was

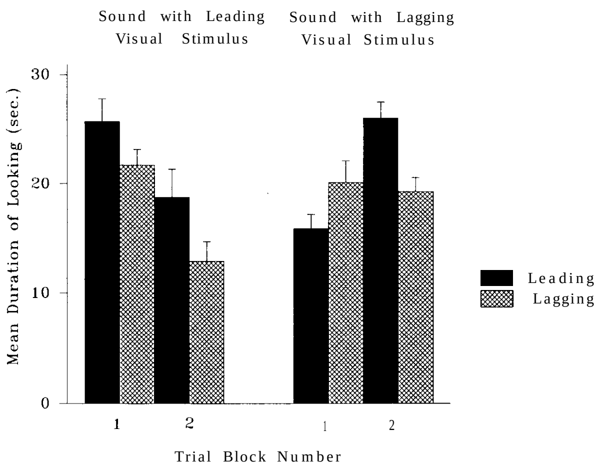

Figure 4. Mean duration of looking at the two visual stimuli as a function of which visual stimulus the sound was synchronized with and as a function of trial block. The data depicted are for the velocity condition in the 8-month-old infants.

a marked effect of block order, $F(1, 22) = 22.26$, $p < .01$, which was due to an overall decrease in looking in the second block of trials (Figure 4). In contrast to the younger infants, however, there was no block order by stimulus interaction. As a result, the data from the two blocks were combined and analyzed together. This analysis indicated that the infants looked significantly longer at the sounding-leading stimulus than at the silent-lagging stimulus, $F(1, 22) = 4.62$, $p < .05$ (Figure 4). Analyses of the data from the trials where the sound was associated with the lagging stimulus indicated that there were no significant effects.

A comparison of looking at the leading stimulus when its direction reversal was synchronized with the sound versus when it was not showed that looking was greater when the sound was synchronized with it in the first block of trials, $t(11) = 3.56$, $p < .01$, and that this preference became reversed in the second block of trials, $t(11) = 3.35$, $p < .01$. Looking at the lagging stimulus was greater when it was synchronized with the sound, but only in the second block of trials, $t(11) = 3.66$, $p < .01$.

Medium-Velocity Condition. In the medium-velocity condition, there was also a significant stimulus × sound condition interaction, $F(1, 22) = 4.60$, $p < .05$. Separate analyses for the two sound conditions showed that for the trials where the sound corresponded to the leading visual stimulus, there was a significant effect of block order, $F(1, 22) = 12.90$, $p < .01$, with looking being greater in the first than in the second block of trials (see Figure 5). Because there was no stimulus × block order interaction, the data from the

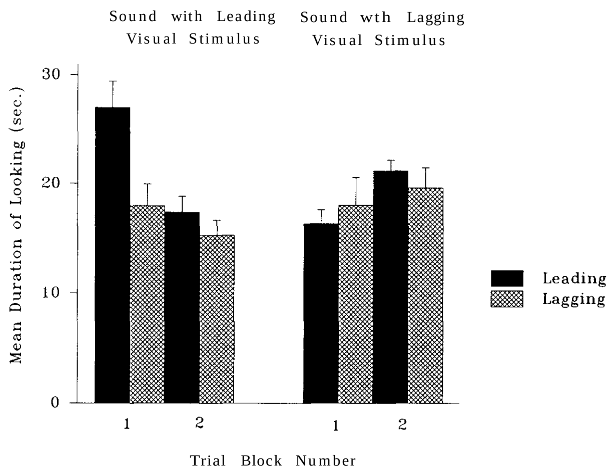

Figure 5. Mean duration of looking at the two visual stimuli as a function of which visual stimulus the sound was synchronized with and as a function of trial block. The data depicted are for the velocity condition in the 8-month-old infants.

two blocks were combined and analyzed together. This analysis indicated that there was an overall stimulus effect, $F(1, 22) = 7.79$, $p < .025$, with infants looking longer at the sounding-leading stimulus than at the silent-lagging one (Figure 5). Analyses of the data from the trials where the sound corresponded to the lagging stimulus indicated that there were no significant effects.

Analyses of looking at the leading stimulus indicated that the infants looked longer at this stimulus when its direction reversal was synchronized with the sound than when it was not in the first block of trials, $t(11) = 4.30$, $p < .01$, but that this preference was reversed in the second block of trials, $t(11) = 2.46$, $p < .05$. Looking at the lagging stimulus was greater when it was synchronized with the sound than when it was not, but only in the second block, $t(11) = 2.59$, $p < .05$.

Fast-Velocity Condition. With one exception, none of the analyses indicated that there was intersensory matching in the fast-velocity condition (Figure 6). The one exception was that the infants did look longer at the leading stimulus when the sound was synchronized with its direction reversal than when it was not in the first block of trials, $t(11) = 3.15$, $p < .01$. Analyses of the frequency and duration of first looks did not indicate any systematic effects that would suggest intersensory matching.

Discussion

The results from this experiment indicate that rate differences did indeed contribute to the infants' failure to make intersensory matches in Experiment 1. When rate differences were eliminated, infants at both ages exhibited

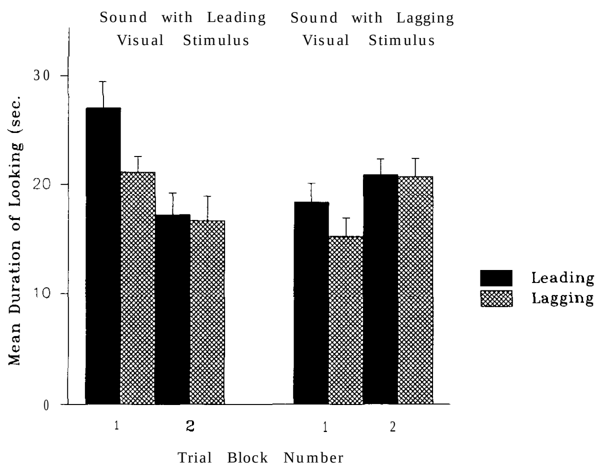

Figure 6 Mean duration of looking at the two visual stimuli as a function of which visual stimulus the sound was synchronized with and as a function of trial block. The data depicted are for the velocity condition in the 8-month-old infants.

evidence of intersensory matching. The strongest and most consistent differential effects were found in the first block of trials and those were primarily evident in a preference for the leading stimulus when its direction reversal was synchronized with the sound. Specifically, at the two slower velocities, the sound had a different effect on looking preferences when it was synchronized with the direction reversal of the leading stimulus than when it was synchronized with the lagging stimulus. Moreover, when the sound was synchronized with the direction reversal of the leading stimulus, the infants looked longer at it than at the lagging stimulus. Finally, the infants looked longer at the leading stimulus when a sound accompanied its direction reversal than when it did not. In fact, infants of both ages exhibited this preference, and did so even at the fastest velocity, where no other effects that would suggest intersensory matching were found. It is also noteworthy that, overall, the strongest effects for all the different types of comparisons were found in the first block of trials. One possible reason for this overall decrease in attention may be a general loss of interest in the task by the second block of trials.

Although the results from the 4-month-old infants confirm, in part, previous findings (Spelke, 1979; Spelke et al., 1983), the results from both age groups in this experiment suggest that infants' ability to respond to temporally based auditory-visual correspondence is limited primarily to those instances where intersensory correspondence is specified by synchrony, without accompanying rate variations. These findings also indicate that responding to the kinds of intersensory relationships presented here does not appear to improve between 4 and 8 months of age.

The phase relationship of the two visual stimuli appeared to play an important role because infants at both ages exhibited the clearest evidence of intersensory matching when the sound was synchronized with the direction reversal of the leading stimulus. Although there was also some evidence of intersensory matching when the sound was synchronized with the lagging stimulus, this was a weaker effect. It was only present at the medium velocity in the younger infants, and at both the slow and the medium velocities in the older infants. What made this effect interesting is that it only appeared in the second block of trials, suggesting that this was a more difficult relationship to detect and that the infants needed more time to discover it.

It could be argued that the differential looking in the presence of the sound that was synchronized with the leading stimulus merely reflected a preference for the leading stimulus. Had that been the case, however, the infants would have looked longer at the leading stimulus regardless of whether the sound was synchronized with it or not. That was not the case. The infants did not look longer at the leading stimulus when its direction reversal was not associated with the sound; they only looked at it longer when the sound was associated with it.

One possible explanation for the differential looking being evident primarily on those trials when the sound was synchronized with the leading stimulus may be that because of greater initial orienting towards the leading stimulus, the infants had more opportunities for noticing the synchrony. For this to be the case, the number of first looks towards the leading stimulus should be greater than the number of first looks towards the lagging stimulus. An analysis of first looks revealed that at 4 months of age, out of 48 trials (2 per each velocity), 40 were directed at the leading stimulus in the slow pair and 31 were directed at the leading stimulus in the intermediate-velocity pair. At 8 months of age, 46 first looks were directed at the leading stimulus in the slow pair, and 39 were directed at the leading stimulus in the intermediate-velocity pair. The lower number of first looks in the intermediate-velocity condition was likely due to the fact that the interval between the appearance of the leading and lagging stimulus was shorter. Though obviously post hoc in nature, the analysis of first looks at least suggests that the infants had the opportunity to notice the optical-acoustic correspondence more often than not.

GENERAL DISCUSSION

These findings indicate that infants between 4 and 8 months of age possess some capacity for relating auditory-visual events consisting of moving visual stimuli and periodic sounds on the basis of their temporal attributes. At the same time, however, they indicate that this capacity is limited even as late as 8 months of age. The 4-month-old infants did not exhibit any evidence of intersensory matching in a choice task as long as the two visual stimuli differed in velocity and/or rate. Because the 4-month-olds exhibited only weak evidence of discrimination when the auditory-visual correlation was disrupted, and because they exhibited no evidence of discrimination when the auditory component was eliminated altogether, their failure to respond to the auditory-visual correlation in the choice task may have, in part, stemmed from a general limitation in the detection of the auditory-visual correlation. Yet, the fact that they exhibited evidence of intersensory matching when velocity and/or rate differences were eliminated suggests that it was the presence of concurrent rate differences that made it difficult for the infants to make the intersensory matches in the choice task. Surprisingly, even the &month-old infants failed to exhibit any evidence of intersensory matching when velocity and/or rate differences were present. This was true despite the fact that they, in contrast to the 4-month-olds, detected both the disruption of the auditory-visual relationship, as well as the absence of the auditory component in the discrimination task. Similar to the 4-month-old infants, the only instance where the older infants exhibited evidence of intersensory matching was when velocity and/or rate differences were eliminated.

One reason that might possibly account for the failure of the infants in Experiment 1 (as well as in those mentioned in Footnote 1) to make intersensory matches might be the absence of a visible surface. The presence of a visible surface might make the situation more perceptually "realistic" and might make the detection of the co-occurrence of the sound and the change in the direction of motion more perceptible. At the same time, however, it should be noted that there are a number of facts that suggest that the presence of a visible surface is not necessary. First, the 8-month-olds discriminated the change in the auditory-visual relation in Experiment 2. Second, both age groups exhibited intersensory matching in Experiment 3. Third, Spelke et al. (1983) found that the infants in their experiments detected intersensory correspondence despite the absence of a visible surface. It thus appears that the critical aspect of the visual event that infants rely on for their intersensory response in this situation is the direction reversal.

The failure of the infants at either age to respond differentially when velocity and/or rate differences were present is at variance with Spelke's (1979) findings of successful auditory-visual matching of rate. It was suggested earlier that the successful intersensory matching of rate obtained by Spelke (1979), and the failure to obtain matching in all the other studies using spatially static visual stimuli, may have been due to the availability of motion cues in Spelke's study. The fact that no evidence of intersensory matching was obtained in Experiment 1, however, makes this possibility an unlikely one. As a result, the only significant difference that remains between Spelke's experiment and the current ones is that the visual stimuli in the current experiments were computer-generated graphical displays and the auditory stimulus was a spectrally complex sound, whereas Spelke's visual stimuli were images of stuffed animals and the sounds were produced by one object making an impact sound against another object. It might be argued that the more "artificial" nature of the stimuli used in the current experiments accounts for the failure to obtain matching. This cannot, however, be the explanation because (a) other studies using artificial stimuli such as checkerboards and tones (Lewkowicz, 1986) obtained positive evidence of intersensory matching, (b) the artificial stimuli used in Experiment 1 yielded evidence of intersensory processing in Experiments 2 and 3, and (c) even when stimuli that might be considered more "realistic" were used (Bahrick, 1987), and when a method of stimulus presentation similar to that of Experiment 3 was used, no evidence of intersensory matching was obtained.

The fact that even the 8-month-old infants did not respond to the intersensory correspondence of rate suggests that intersensory processing of rate may have a different basis than does the intersensory processing of synchrony in early development. The failure to find intersensory matching of rate with kinetic stimuli in the current experiments is in large measure consistent with the failure of prior experiments to find intersensory matching of rate with spatially static stimuli (Lewkowicz, 1985, 1989b). As noted earlier, Lewkowicz (1985) failed to find intersensory matching of rate in 4-month-old infants, and reported a failure to obtain intersensory matching with rates of 2, 4, and 8 Hz. even as late as 10 months of age (Lewkowicz, 1989b). Only with slower rates did Lewkowicz obtain some evidence of intersensory matching at 8 months of age but not before. This is consistent with adult data showing that cross-modal matching of rhythmic auditory-visual patterns consisting of more than three stimulus elements per second is more difficult than matching of patterns consisting of fewer than three stimulus elements per second (Rubinstein & Gruenberg, 1971).

The finding of successful intersensory matching when synchrony signalled the intersensory correspondence, but of no matching when concurrent rate differences were present, is, in a general sense, consistent with Bahrick's (1987) results of temporally based intersensory matching. Bahrick also found that infants exhibited more difficulty in making intersensory matches when the visual information was more complex. Those findings suggest that synchrony may be a critical temporal attribute that underlies infants' early intersensory responsiveness to auditory-visual events. For example, Lewkowicz (1986) found that synchrony played a critical role in 6-month-old infants' intersensory matches of duration. When the synchronous relationship between the occurrence of a sound and the onset and offset of a flashing checkerboard was disrupted, infants no longer exhibited intersensory matching. Bahrick (1987) also found that synchrony played a critical role in intersensory matching in that 6-month-old infants detected the temporal relationship between a moving object and a sound that was synchronized with the reversal in its direction of motion, but they did not do so when the direction reversal was not synchronized with the sound. Spelke's most robust findings come from experiments where synchrony was the temporal attribute that infants had to respond to. Finally, Lawson (1980) showed that 6-month-old infants can learn to associate arbitrary pairings of a sound synchronized with the direction reversal of a moving object. The one exception to this set of findings on synchrony is Kuhl and Meltzoff's (1982) finding that 4-month-old infants looked preferentially at a face articulating a vowel that they heard simultaneously, but that they did not show differential fixations when the linguistic content of the vowels was removed and only the duration, intensity, and synchrony characteristics of the vowels were preserved. It is possible, however, that synchrony may not begin to serve the role of intersensory integrator until somewhere between 4 and 6 months of age, as would be suggested by the Lewkowicz (1986) data. Also, the failure of the infants in the Kuhl and Meltzoff experiment to make the bisensory matches when the "linguistically stripped" auditory stimulus was presented may have less to do with the infant's capacity to process intersensory relationships on the basis of synchrony than with the fact that the linguistically stripped auditory stimulus does not allow the intersensory integration to take place because the linguistic expectation is violated.

Consequently, it seems that synchrony is a very basic intersensory attribute that serves to unite multimodal sources of stimulation at early stages of development. It would, indeed, be parsimonious for a developing system to rely on synchrony as a cue for auditory-visual integration because synchrony typically accompanies any variations in other temporal dimensions of multimodal inputs such as repetition rate, duration, and rhythm. Having synchrony as an intersensory cue might permit infants to achieve the first stage in integration of temporally based inputs that can then be followed by integration based upon other temporal properties. In other words, intersensory responsiveness to the other temporal dimensions of stimulation such as rate, duration, and rhythm might be expected to occur later in development. Experiments to date have only shown that when synchrony is disrupted, infants no longer respond to the intersensory correspondence. What remains to be demonstrated is that older infants can detect intersensory correspondence based on rate, duration, or rhythm in the absence of synchrony.

REFERENCES

Allen, T.W., Walker, K., Symonds, L., & Marcell, M. (1977). Intrasensory and intersensory perception of temporal sequences during infancy. *Developmental Psychology, 13, 225-229.*

Bahrick, L.E. (1983). Infants' perception of substance and temporal synchrony in multimodal events. *Infant Behavior and Development, 6, 429-451.*

Bahrick, L.E. (1987). Infants' intermodal perception of two levels of temporal structure in natural events. *Infant Behavior and Development, 10, 387-416.*

Bahrick, L.E. (1988). Intermodal learning in infancy: Learning on the basis of two kinds of invariant relations in audible and visible events. *Child Development, 59, 197-209.*

Dodd, B. (1979). Lip reading in infants: Attention to speech presented in-out-of-synchrony. *Cognitive Psychology, I I, 478-484.*

Humphrey, K., & Tees, R.C. (1980). Auditory-visual coordination in infancy: Some limitations of the preference methodology. *Bulletin of the Psychonomic Society, 16, 213-216.*

Kuhl, P.K., & Meltzoff, A.N. (1982). The bimodal perception of speech in infancy. *Science, 218, 1138-1140.*

Lawson, K.R. (1980). Spatial and temporal congruity and auditory-visual integration in infants. *Developmental Psychology, 16, 185-192.*

Lewkowicz, D.J. (1985). Bisensory response to temporal frequency in 4-month-old infants. *Developmental Psychology, 21, 306-317.*

Lewkowicz, D.J. (1986). Developmental changes in infants' bisensory response to synchronous durations. *Infant Behavior and Development, 9, 335-353.*

Lewkowicz, D.J. (1988a). Sensory dominance in infants I: Six-month-old infants' response to auditory-visual compounds. *Developmental Psychology, 24, 155-171.*

Lewkowicz, D.J. (1988b). Sensory dominance in infants II: Ten-month-old infants' response to auditory-visual compounds. *Developmental Psychology, 24, 172-182.*

Lewkowicz, D.J. (1989a). The role of temporal factors in infant behavior and development. In I. Levin & D. Zakay (Eds.), *Time and human cognition: A life-span perspective.* Amsterdam: North Holland.

Lewkowicz, D.J. (1989b, April). *Infants' auditory/visual matching of rate with spatially-static visual stimuli*. Poster presented at the meeting of the Society for Research in Child Development, Kansas City, MO.

Lewkowicz, D.J. (1991). Development of intersensory functions in human infancy: Auditory/visual interactions. In M.J. Weiss & P.R. Zelazo (Eds.), *Newborn attention: Biological constraints and the infruence of experience*. Norwood, NJ: Ablex.

Lewkowicz, D.J. (in press). Infants' responsiveness to the auditory and visual attributes of a moving and sounding stimulus. *Perception and Psychophysics*.

Mendelson, M.J., & Ferland, M.B. (1982). Auditory-visual transfer in four-month-old infants. *Child Development, 50, 747-75 1*.

Moore, D.S.G., & Gibbons, J.L. (1988, April). *Early auditory and visual integration in d-month-old infants*. Poster presented at the International Conference of Infant Studies, Washington, DC.

Rose, S.A., & Ruff, H.A. (1987). Cross-modal abilities in human infants. In J.D. Osofsky (Ed.), *Handbook of infant development*. New York: Wiley.

Rubinstein, L., & Gruenberg, E.M. (1971). Intramodal and crossmodal sensory transfer of visual and auditory temporal patterns. *Perception and Psychophysics, 9, 385-390*.

Sokolov, E. (1963). *Perception and the conditioned reflex*. New York: Pergamon.

Spelke, E.S. (1979). Perceiving bimodally specified events in infancy. *Developmental Psychology, 15, 626-636*.

Spelke, E.S., Born, W.S., & Chu, F. (1983). Perception of moving, sounding objects by four-month-old infants. *Perception, 719-732*.

Walker, A.S. (1982). Intermodal perception of expressive behaviors by human infants. *Journal of Experimental Child Psychology, 33, 514-535*.

25 October 1990; Revised 30 July 1991