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Developmental Changes in Infants' Bisensory Response to Synchronous Durations

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The present set of studies was concerned with the development of bisensory response to synchronous durations. Infants viewed pairs of checkerboards where each member of the pair flashed at the same rate but differed in the duration of each flash. Visual preferences were studied in silence as well as in the presence of a tone whose duration and onset/offset characteristics corresponded to one member of the visual pair of stimuli. Results indicated that 3-month-old infants did not make bisensory matches of duration. In contrast, 6- and 8-month-old infants exhibited evidence of bisensory matching in that, in general, their looking at the visual stimulus corresponding in duration to the auditory stimulus was greater than was their looking at the non-corresponding stimulus. Synchrony played a major part in this matching in that when the corresponding auditory and visual stimuli were put out of phase with one another, no evidence of bisensory matching was obtained.

The capacity of the perceiver to relate information registered by different sensory systems forms the basis for many of our higher level cognitive, perceptual, affective, and linguistic functions (Geschwind, 1965). Intersensory integration of equivalent information requires that the perceiver first be able to detect the specific stimulus properties contained in the information available to each modality and then extract and relate the equivalent aspects of that information across modalities. Because of their ubiquity and amodal character, temporal aspects of stimulation are an important and rich source of information and provide many opportunities for intersensory integration. For example, the temporal synchrony of a seen and heard speech message is very important for the accurate perception of the message; introduction of a temporal delay of as little as 400 ms between the seen and heard version of the message leads to an appreciable drop in adults' ability to correctly identify it (Dodd, 1977). Presumably, the asynchrony between the visual and auditory components of the message interferes with the subject's ability to extract and match the equivalent temporal information that is specified by the movement of the mouth and the temporal distribution of acoustic energy.

A number of studies have examined infants' ability to integrate temporal information across different modalities (Allen, Walker, Symonds, & Marcell, 1977; Bahrick, 1983; Gardner, Lewkowicz, Rose, & Karmel, in press; Humphrey, Tees, & Werker, 1979; Lewkowicz, 1985a; Mendelson & Ferland, 1982; Spelke, 1979, 1981). This work has focused on response to rhythmicity, temporal synchrony, and temporal frequency. Conspicuously absent from this list is duration. This is somewhat surprising since duration is probably one of the most basic of temporal parameters (Fraisse, 1963) and one which is the basis for all the other temporal variations. For example, production of different rhythmic sequences or of sequences having different temporal frequencies involves the manipulation of the duration of the interstimulus intervals separating each member of the sequence. Discrimination of differences in a rhythmic pattern or in temporal frequency must therefore, at least in part, depend on the subject's ability to discriminate these duration differences. As a result, the data from the existing studies might be interpreted as indirect evidence of bisensory integration of duration by at least 4 months of age. However, in addition to carrying information about duration, sequences varying in their rhythmic structure carry pattern information, while sequences differing in temporal frequency carry information about tempo. Consequently, the data from these studies cannot be taken as direct evidence of bisensory integration of duration information.

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In addition to the absence of direct studies of intersensory integration of duration, no studies have examined possible developmental changes in intersensory response to temporal properties of stimulation. In the absence of any data on possible changes in intersensory functioning during early development, one is forced to look to theory for guidance. So far, theoretical discussions of the fate of intersensory integration during early development have involved the postulation of one of two opposing views. The integration view holds that the senses operate separately from one another at birth and that during development there is gradual integration of their activity (Birch & Lefford, 1967; Piaget, 1952). The differentiation view holds that intersensory integration is present from birth and that a process of differentiation characterizes development (Bower, 1974; Gibson, 1969). Gibson (1969), for example, argues that perception consists of the direct detection of the information that specifies the invariant properties of objects and events and that as a result no mediation, integration, or association is necessary for perception to occur. According to this view, the infant's world is already highly structured and events and objects possess multimodal properties. The development of intersensory integration consists of the differentiation of an increasingly greater number of the amodal invariants that are already present in the infant's world.

Thus, from the integration point of view, detection of intersensory equivalence of duration should appear somewhere in early development, although it is not clear when and what specific mechanism might make this possible. The differentiation position, on the other hand, would lead one to expect that the infant should be able to detect intersensory equivalence based on some basic amodal properties of stimulation right from birth, while detection of other more complex amodal properties may not occur until sometime later. One problem with such a view is that it is difficult to predict a priori which amodal invariants infants should detect at a given point in development. A second problem is that this view is an either/or proposition; the infant is either capable of detecting the amodal invariant or is not. If the infant is not, then it is merely a matter of time before he/she is. There is no room for the possibility that a different mechanism may be operating which may allow input from different sensory modalities to influence one another (Lewkowicz, 1985a; Lewkowicz & Turkewitz, 1981) but one which does not permit the detection of equivalence. The third, and most serious problem, is that the Gibsonian position places an undue emphasis on the information in the perceiver's world to the exclusion of the possible influence that the organism's level of functional organization may have on responsiveness. As is well known, the infant and his/her sensory systems undergo major changes in early development (Banks & Salapatek, 1984). This certainly has major consequences for the way the infant responds to the external world.

It would therefore seem that a more productive conceptual approach towards understanding the development of intersensory integration would be one that not only takes into account factors such as the nature of the stimulation presented and the nature of the task presented to the infant, but also the specific characteristics and capacities of the particular sensory systems involved, the infant's prior experience, and the known functional characteristics of the infant at the particular point of development. Recognition of all these factors leads to much more specific predictions regarding intersensory functioning, allows for a broader understanding of the mechanisms involved in the development of intersensory integration, and gets us away from viewing the development of intersensory integration as a unitary process (Ettlinger, 1977).

One example of the utility of this approach is its capacity to provide a possible resolution of a seeming discrepancy regarding intersensory response to temporal frequency that has recently appeared in the literature. Spelke (1979) has reported that 4-month-old infants are able to detect the equivalence between the rate of presentation of a sound and the rate of presentation of one of two stuffed animals whose movement corresponds in rate to the sound. Lewkowicz (1985a), on the other hand, has found no bisensory matching of a temporally modulated sound with a corresponding member of a pair of flashing checkerboards. Instead, he found that the overall stimulative value of the sound determined the nature of the overall preference function such that the faster (i.e., the more stimulating) sound produced a decrease in looking at the fastest stimulus and a concomitant increase in looking at the slower stimuli. When viewed in terms of the aforementioned factors, rather than being seen as contradictory, the findings from these two sets of studies may be viewed as complementary since they raise the possibility that the specific nature of the stimuli used in the two sets of studies may bring into operation different mechanisms of sensory/perceptual functioning. In this way our understanding of the necessary and sufficient conditions for different types of intersensory integration at this particular stage in development is further broadened.

STUDY 1

The aim of this study was to determine whether infants are able to detect auditory-visual equivalence based on synchronous durations and whether any developmental changes in this ability occur during infancy. The paired-comparison method was used to assess infants' visual preferences for one of two flashing checkerboards. These checkerboards flashed at the same rate, but differed in the duration of each flash. For each infant preferences were studied in silence as well as in the presence of a sound that on some trials corresponded in duration to one member of the pair of visual stimuli and on others to the other member of the pair. The onset of the sound was synchronous with the onset of both visual stimuli, but its offset was only synchronous with the offset of one member of the visual pair of stimuli. As a result, the sound and the visual stimulus whose offset was synchronous with the offset of the sound were also equal in duration.

In general, the procedures used in these studies were expected to lead to differential looking in the different sound conditions. For example, it was expected that for a given pair of visual stimuli, looking at one member of the pair would be greater in the presence of the corresponding sound than in the presence of a sound that corresponded to the other member of the pair. Also, looking at one member of the pair in the presence of the corresponding sound would be greater than looking in silence. There are two reasons why this outcome would be expected. First, there is a large and well-known body of work with adults which has demonstrated the existence of the "ventriloquism effect" (Jack & Thurlow, 1973) or the "visual capture effect" (Hay, Pick, & Ikeda, 1965). In either case this effect refers to the tendency of a subject to perceive the source of an auditory stimulus, that unbeknownst to him/her is displaced from a visual stimulus, as coming from that visual stimulus. In other words, as long as there is some relationship between the visual and auditory stimuli (usually it is temporal in nature) the perceptual system imposes unity even though a discrepancy in location of the two stimuli exists. Second, as already indicated, data from prior studies with infants indicate that they tend to look longer or more frequently at the visual stimulus that corresponds to the auditory stimulus. Presumably, the basis for this effect in infants is the same as in the adults.

Method

Subjects. A total of 43 infants served as subjects. Thirteen 3-month-old infants (3 boys, 10 girls), ranging in age from 13 weeks, 6 days to 15 weeks (*M* = 14 weeks, 2 days), were tested. An additional 8 infants were tested at this age, but were excluded from data analysis. Four were excluded due to fussing or crying, 2 due to sleepiness, and 2 due to inattentiveness. Sixteen 6-month-old infants (8 boys, 8 girls), ranging in age from 27 weeks to 29 weeks, 3 days (*M* = 28 weeks), were tested. An additional 9 infants were tested at this age but were excluded from data analysis. Four were excluded due to fussing, 1 due to equipment failure, 1 due to experimenter error, and 3 due to inattentiveness. Fourteen 8-month-old infants (8 boys, 6 girls), ranging in age from 36 weeks, 2 days to 37 weeks, 2 days (*M* = 36 weeks, 6 days) were tested. Two additional infants were tested but were excluded from data analysis due to fussing or crying.

All of the infants were fullterm at birth, with uncomplicated perinatal histories, and were in good health at the time of testing.

Apparatus and Stimuli. During testing the infant sat inside a three-sided chamber designed so that the two lateral walls obstructed his or her view of the laboratory. The wall facing the infant was covered with black posterboard and had two openings, each covered with a light diffuser (milk-white Plexiglas). Each diffuser was covered with a transparency of a black and white check pattern made up of a random arrangement of ½-inch (1.27 cm) checks. This check pattern was a replica of the random ½-inch pattern used by Karmel (1969). Each opening measured 15x15 cm, and the inner edges of the openings were 23.5 cm apart. At a viewing distance of 43 cm each checkerboard subtended 19°18' of visual angle. Each check pattern was lighted from behind the diffuser by two 14-watt fluorescent bulbs which operated silently and which were housed inside a 50x18x23 cm box. To permit an essentially instantaneous onset, these bulbs were kept "warm" by applying 9 volts dc to them during the "off" periods. To light the bulbs, 300 volts dc was applied to them. During stimulation, the luminance of the white squares in the patterns was 6.4 footlamberts (21.92 cd/m^2), whereas the luminance of the black squares was approximately 0 footlamberts. Visual fixations were observed through a .64-cm peephole located in the center of the wall facing the infant. An Apple computer was used to measure and store the duration of visual fixations. A set of five colored LEDs arranged in a cross configuration was located in the center between the two visual stimuli and was used to attract the infants' attention during the interstimulus intervals. A Quam 8 ohm, 4-inch (10.16 cm) speaker was placed beneath the central fixation display midway between the visual stimuli. The auditory stimulus was a 1000 Hz tone which measured 72 dB at the infant's ear (re .0002 dynes/cm^2, A scale). The rise time of the tone was 10 ms and was controlled by a Grason-Stadler electronic switch for the 6- and 8-month-old infants and by a Coulbourn Instruments rise/fall switch for the 3-month-old infants.

A custom-built pulse generator was used to control the temporal parameters of the stimuli. Two independent channels of the generator controlled the "on" and "off" periods of each of the two visual stimuli. The onset of the two visual stimuli was always synchronous. One of the two channels also controlled the on and off periods of the auditory stimulus. As a result, the onset of the auditory stimulus was always synchronous with the onset of both visual stimuli and synchronous with the offset of the visual stimulus to which it corresponded. Gating of the stimuli was accomplished by having the square-wave output of each channel of the generator drive a silent relay, which, in turn, controlled the onset of the stimuli. Three durations of stimulation were used in this study: 400, 800, and 1600 ms. During a given trial each stimulus was repeatedly presented once every 2 s.

Procedure. Testing took place in a dimly illuminated room. The ambient sound pressure level in the room, as measured at the infant's ear, was 46 dB (re .0002 dynes/cm^2, A scale). The 3-month-old infants were placed in a semireclining position in a commercially available infant seat at a distance of approximately 43 cm from the stimuli. The 6- and 8-month-old infants were seated on their parent's lap. The stimulus pair was presented only when the infant fixated the colored lights in the center between the stimuli. As soon as the infant's gaze was judged to be in the center, the trial was initiated by turning the stimuli on. Each trial lasted 15 s. The intertrial interval was determined by the infant since the next trial was not initiated until he/she looked in the center. The observer monitored the direction of gaze and recorded the duration of looking to the right or left by depressing a switch which was connected to the Apple computer. Because it was rather easy to see the reflection of the stimuli on the infant's cornea, it was not possible for the observer to be blind with respect to the durations of the stimuli. To establish reliability, a second observer, who was unaware of the details of experimental procedure and hypotheses and who could not tell what stimuli the infant was looking at, viewed and scored visual fixations from videotaped records. An interobserver reliability of .97 was obtained between the experimenter and the blind observer.

Each infant was presented with a series of 18 trials. The first 6 silent trials consisted of the presentation of the visual stimuli without the accompanying auditory stimulus. All possible pairs of the three durations (counterbalanced for side) were presented. To counterbalance for order effects, this series of 6 trials was presented according to one of six possible orders. Across these six orders each pair appeared an equal number of times at each ordinal position and a given stimulus was not followed by itself on the same side.

The remaining 12 trials comprised the sound trials. During the first trial of this series a given pair of visual stimuli was presented with an accompanying sound whose duration corresponded to the duration of one member of the visual pair of stimuli. The next trial consisted of the presentation of the same pair of visual durations, but reversed in lateral position, together with the same-duration sound as in the preceding trial. This procedure was repeated until each duration of auditory stimulation was presented together with all visual pairs containing the corresponding duration of visual stimulation. A given duration of auditory stimulation was never presented together with a visual pair where neither member of that pair corresponded in duration to the duration of sound presentation. To control for order effects, each infant was administered these trials according to one of six orders which were generated by considering each set of the 2 consecutive trials involving the same visual pair as a single trial.

Data Analysis. One analysis was based on the proportion of looking at each stimulus. These proportions were derived by collapsing across the two 15-s trials involving reversal of the lateral position of the stimuli and then dividing the total amount of looking at each member of the pair by the total amount of time spent looking at both members of the pair.

These proportion scores were first submitted to an overall analysis and consisted of an examination of the proportion of looking at one member of a pair of visual stimuli as a function of auditory condition. This overall analysis was a three-way analysis of variance (ANOVA) with Age as the between-subjects factor and Pair and Sound condition as the within-subjects factors. Since no significant interaction effects were found, the data for each age were analyzed separately. Within each age a separate analysis was done for each pair. For example, for the 400-1600 ms pair, a one-way, repeated-measures ANOVA was done on the proportion of looking at the 1600-ms stimulus when it was presented (a) together with the 400-ms sound, (b) in silence, and (c) with the 1600- ms sound. The overall ANOVAs were then followed by planned comparisons (as outlined previously) to determine the source of significant overall effects. These analyses were then supplemented by an examination of the raw data to clarify the source of the differences resulting from the proportion data.

Results and Discussion

Three-Month-Old Infants. Separate analyses of the data from each of the three pairs revealed that there was no evidence of bisensory matching in any of the pairs (see Figures 1-3). Table 1 shows the means and standard deviations of the raw data for these infants.

Six-Month-Old Infants. Separate analyses of the data from each of the three pairs revealed that although there was no evidence of matching in the 400-800 ms pair (see Figure 1), there was clear evidence of bisensory matching in both the 400-1600 ms pair and in the 800-1600 ms pair.

As can be seen in Figure 2, for the 400-1600 ms pair, the mean proportion of looking at the 1600-ms stimulus was greater when this stimulus was presented together with the 400-ms sound or in silence. A one-way ANOVA, with Sound Condition as the repeated factor, indicated that the effect of Sound Condition on proportion of looking at the 1600-ms stimulus was, in fact, significant, $F(2,30)=3.64$, $p<.05$. Planned comparisons showed that the proportion of looking at the 1600-ms stimulus was greater when this stimulus was presented together with the 1600-ms sound than when it was presented together with the 400-ms sound, $t(15)=2.15$, $p<.025$, or in silence, $t(l5)=2.44$, $p< .025$. Because the proportion of looking at the 400-ms stimulus is a complement of the proportion of looking at the 1600-ms stimulus, the differential effects of the 400- and the 1600-ms auditory stimuli can also be interpreted as evidence that the infants were making matches of the 400-ms visual and auditory stimuli.

To further clarify these effects, separate analyses of the raw data were done (see Table 1). These analyses revealed that the differences found in the analyses of the proportion data were due to both greater looking at the 1600-ms stimulus in the presence of the 1600-ms sound than in the presence of the 400-ms sound, $t(15)= 2.58$, $p< .025$, and to greater looking at the 400-ms stimulus in the presence of the 400-ms sound than in the presence of the 1600-ms sound, $t(15)= 1.76$, $p< .05$. Furthermore, the amount of looking at the 1600-ms stimulus in the presence of the 1600-ms sound was greater than was the amount of looking at the same stimulus in silence, $t(15)== 1.94$, $p<.05$.

As can be seen in Figure 3, for the 800-1600 ms pair, the mean proportion of looking at the 1600-ms stimulus was also greater when this stimulus was presented together with the 1600-ms sound than when this stimulus was presented together with the 800-ms sound or in silence. A one-way ANOVA, with sound condition as the repeated factor, indicated that the effect of sound condition on proportion of looking at the 1600-ms stimulus was significant, F(2,30)= 5.90, $p< .01$. Planned comparisons showed that. the proportion of looking at the 1600-ms stimulus when it was presented together with the 1600-ms sound was greater than was the proportion of looking at the 1600-ms stimulus when it was presented together with the 800-ms sound, $t(15)=1.91$, $p<.05$, or in silence, $t(15)=3.76$, $p<.005$. The fact that the proportion of looking at the 1600-ms stimulus was greater in the presence of the 1600-ms sound than it was in the presence of the 800-ms sound also means that the proportion of looking at the 800-ms stimulus was greater in the presence of the 800-ms sound than it was in the presence of the 1600-ms sound.

TABLE 1

Means and Standard Deviations of Infants' Looking Time (Seconds) for Each Pair of Visual Durations as a Function of Different Auditory Conditions

Sound Condition	**400 - 800**		**400 - 1600**		**800 - 1600**	
3-Month-Olds						
Silent						
M	9.6	13.5	10.3	16.3	9.1	16.4
SD	5.5	4.6	9.4	8.5	5.1	2.4
Short						
M	7.4	10.8	6.1	15.0	7.6	14.3
SD	4.2	4.2	3.8	6.8	3.5	5.0
Long						
M	7.8	11.8	5.7	16.6	7.3	16.2
SD	4.2	4.4	3.6	4.2	4.0	6.7
6-Month-Old						
Silent						
M	8.9	12.7	8.8	13.0	12.7	11.1
SD	4.5	5.3	3.2	3.4	4.2	3.5
Short						
M	8.8	12.3	10.0	12.6	11.1	11.8
SD	3.7	4.6	4.0	4.0	4.5	3.4
Long						
M	7.5	13.1	7.5	15.1	7.9	14.4
SD	3.5	4.5	3.1	3.0	3.5	5.9
8-Month-Old						
Silent						
M	7.7	9.7	5.9	10.8	10.8	8.9
SD	3.3	4.3	3.1	4.2	4.9	4.9
Short						
M	7.2	11.2	8.7	11.4	8.6	8.8
SD	4.1	5.0	3.6	4.3	3.3	3.6
Long						
M	7.5	8.8	6.0	13.2	7.8	12.6
SD	4.2	3.7	3.2	4.3	3.6	3.3

Note. For Sound Condition, Silent means that the visual pairs were presented in silence. Short means that they were presented together with the sound corresponding to the shorter member of the pair, and Long means that they were presented together with the sound corresponding to the longer member of the pair.

Analyses of the raw data (see Table 1) showed that these differences were due to marginally greater looking at the 1600-ms stimulus in the presence of the 1600-ms sound than in the presence of the 800-ms sound, $t(15) = 1.57$, $p< .10$, and to greater looking at the 800-ms stimulus in the presence of the 800-ms sound than in the presence of the 1600-ms sound, $t(15) = 2.22$, $p< .025$. Furthermore, the amount of looking at the 1600-ms stimulus was greater in the presence of the 1600-ms sound than it was in silence, $t(15)=2.16$, $p<.025$.

Eight-Month-Old Infants. The results from the 8-month-old infants are essentially a replication of the results from the 6-month-old infants. As was the case for the 6-month-old infants, there was no evidence of bisensory matching in the 400-800 ms pair for the 8-month-old infants (see Figure 1).

As can be seen in Figure 2, for the 400-1600 ms pair, the overall mean proportion of looking at the 1600-ms stimulus was greater when the stimulus was presented together with the 1600-ms sound than when it was presented either in silence or together with a 400-ms sound. A one-way ANOVA, with Sound Condition as the repeated factor, indicated that the effect of Sound Condition was significant, *F*(2,26)= 3.42, *p*<.05. Planned comparisons revealed that the proportion of looking at the 1600-ms stimulus when this stimulus was presented together with the 1600-ms sound was greater than was the proportion of looking when the 1600-ms stimulus was presented together with the 400-ms sound, *t*(13)==3.67, *p*<. 005. These results indicate that each sound duration had a differential effect on the infants' looking at the two durations of visual stimulation and given that the proportion of looking is greater for each stimulus when the concurrent sound matches it in duration, these data are evidence of bisensory matching.

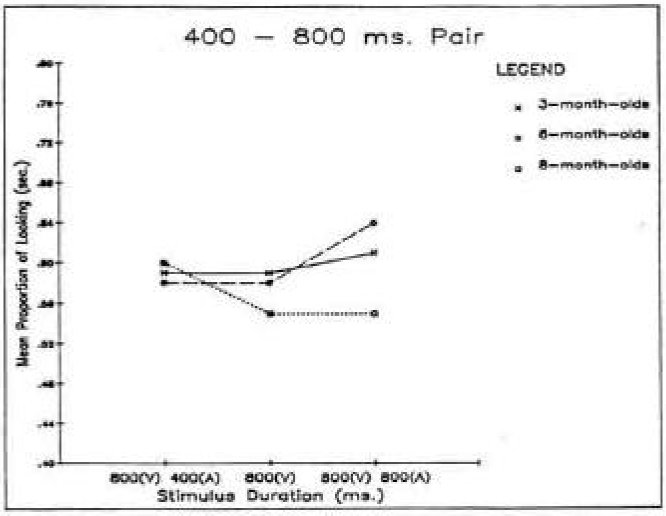

Figure 1. Mean proportion of looking at the 800-ms stimulus when presented together with a 400-ms auditory stimulus, in silence, and with an 800-ms auditory stimulus by 3-, 6-, and 8-month-old infants.

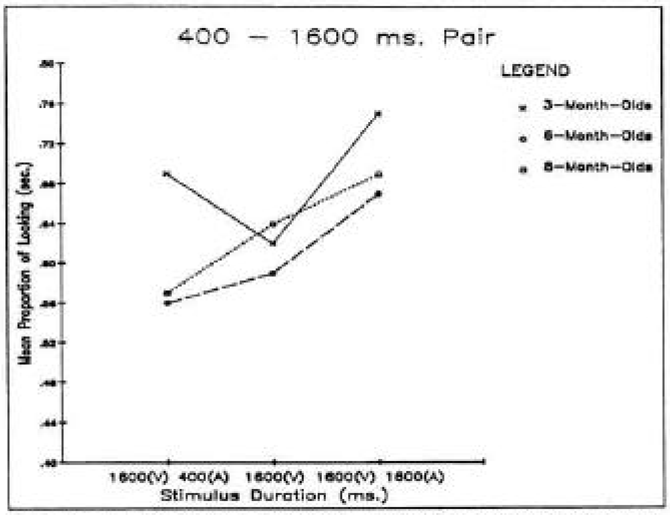

Figure 2. Mean proportion of looking at the 1600-ms stimulus when presented together with a 400-ms auditory stimulus, in silence, and with a 1600-ms auditory stimulus by 3-, 6-, and 8-month-old infants.

Examination of the raw data (see Table 1) indicated that these differences were due to a marginal increase in looking at the 1600-ms stimulus in the presence of the 1600-ms sound relative to looking in the presence of the 400-ms sound, *t*(13)=1.60, *p* < .01, and a significant increase in looking at the 400-ms stimulus in the presence of the 400-ms sound relative to looking in the presence of the 1600-ms sound, *t*(13)= 3.45, *p*<. 005. Furthermore, the amount of looking at the 1600-ms stimulus was greater in the presence of the 1600-ms sound than it was in silence, *t*(13) = 2.34, *p*< .025, and the amount of looking at the 400-ms stimulus in the presence of the 400-ms sound was greater than it was in silence, *t*(13)= 2.09, *p*<. 05.

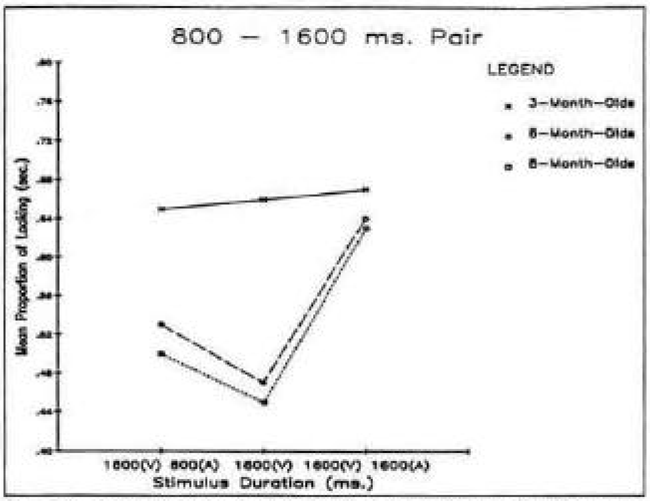

Figure 3. Mean proportion of looking at the 1600-ms stimulus when presented together with an 800-ms auditory stimulus, in silence, and with a 1600-ms auditory stimulus by 3-, 6-, and 8-month-old infants.

As can be seen in Figure 3, for the 800-1600 ms pair, the proportion of looking at the 1600-ms stimulus when it was presented together with the 1600-ms sound was greater than was the proportion of looking at the 1600-ms stimulus when it was presented together with the 800-ms sound or in silence. A one-way ANOVA, with Sound Condition as the repeated factor, indicated that the effect of Sound Condition was significant, *F*(2,26) = 6.96, *p* <.01. Planned comparisons revealed that the difference in the proportion of looking at the 1600-ms stimulus when it was presented together with the 1600-ms sound was greater than was the proportion of looking when this stimulus was presented together with the 800-ms sound, *t*(13)=2.89, *p*<.01, or in silence, *t*(13) = 3.13, *p*<.005.

Examination of the raw data (see Table 1) indicated that the source of this difference was greater looking at the 1600-ms stimulus in the presence of the 1600-ms sound than it was in the presence of the 800-ms sound, *t*(13)= 3.00, *p*<.01. In addition, there was greater looking at the 1600-ms stimulus in the presence of the 1600-ms sound than there was in silence, *t*(13) = 2.28, *p*<.025.

STUDY 2

In most natural situations, when a single event is specified in terms of duration and when that temporal information is available to different sensory modalities, the onset and offset of that duration is by default synchronous in the different modalities. For example, when a rattle is shaken the sound and sight of that rattle lasts the same amount of time and begins and ends at the same time. No doubt, such cue redundancy allows for easier integration of intersensory information. In the previous studies, synchrony, as well as duration, united the visual and auditory stimuli, and the data from the two older groups of infants make it clear that when both duration and synchrony are available, infants 6 months and older are able to make bisensory matches. What is not clear is whether the matching behavior observed in the previous studies was based on duration alone or whether synchrony played a role as well. Thus, in this last study, procedures identical to those used in the previous ones were used except that the onset and offset of the sound were no longer synchronous with the onset and offset of the visual stimulus corresponding in duration.

Method

Subjects. Sixteen infants (10 boys, 6 girls), ranging in age from 35 weeks, 4 days to 37 weeks, 6 days (*M* = 36 weeks, 6 days), were tested. Eight additional infants were tested but were excluded from data analysis. Five were excluded due to fussing, 2 due to inattentiveness, and 1 due to equipment failure.

Apparatus and Stimuli. The apparatus and stimuli were identical to those used in Study 1.

Procedure. The testing procedures were identical to those employed in Study 1 with one exception. During each stimulus cycle the onset of the auditory stimulus was delayed by 300 ms with respect to the onset of the two visual stimuli, and, as a result, its offset was also delayed by 300 ms with respect to the offset of the corresponding visual stimulus. A 300-ms delay was chosen because adults no longer experience the visual capture of auditory localization when the auditory stimulus is delayed by 300 ms with respect to the visual stimulus (Jack & Thurlow, 1973).

Results and Discussion

As in the previous studies, the data from each pair were analyzed separately. In contrast to the data from the previous studies, no significant differences in visual fixation were obtained in this study (see Table 2). This indicates that a phase delay of 300 ms is sufficient to disrupt bisensory matching and suggests that synchrony plays an important role in this process.

TABLE 2 Means and Standard Deviations of Infants' Looking Time (Seconds) for Each Pair of Visual Durations as a Function of Different Auditory Conditions in the Asynchrony Study

Sound Condition	**400**	**800**	**400**	**1600**	**800**	**1600**
Silent						
M	7.2	11.1	7.1	11.3	8.9	10.2
SD	3.2	4.6	5.3	3.2	5.0	5.1
Short						
M	7.9	8.1	6.2	8.9	8.3	8.5
SD	4.8	4.2	3.8	4.2	4.7	3.5
Long						
M	6.4	7.3	6.8	10.1	7.2	8.6
SD	3.2	3.8	4.4	4.8	4.0	3.8

Note. For Sound Condition, Silent means that the visual pairs were presented in silence, Short means that they were presented together with the sound corresponding to the shorter member of the pair, and Long means that they were presented together with the sound corresponding to the longer member of the pair.

Although synchrony appeared to play a very important role in the detection of bisensory equivalence of duration in the previous studies, it also seems that there was an interaction between the duration of the stimulus and synchrony, because matching was not found in all the pairs in the two older groups of infants. That is, if matching were based solely on synchrony, then it should have been evident in all the pairs. The fact that no matching was found for the 400- 800 ms pair suggests that synchrony only facilitates bisensory matching when the difference between the two visual durations is greater than 400 ms.

GENERAL DISCUSSION

When considered together, the data from the present studies point to a developmental change in infants' response to auditory-visual equivalence of synchronous durations. At 3 months of age, infants did not detect the temporally based equivalence. Instead, these infants appeared to attend primarily to the longer (1600 ms) stimulus in the 400-1600 ms and the 800-1600 ms pairs, regardless of whether the stimulus was accompanied either by sound or by silence. In contrast, 6- and 8-month-old infants attended to the specific temporal characteristics of the stimulation and performed bisensory matches. These data are in accord with other recent data showing that by 6 months of age, infants begin to attend to the specific temporal properties of stimulation such as the temporal frequency of stimulation (Lewkowicz, 1985b). In addition, the current set of findings is consistent with studies of differential metabolic activity in different areas of the developing brain (Chugani & Phelps, 1986). These studies have shown that at 3 months of age, metabolic rate in the frontal cortex and several association areas was lower than that observed in the rest of the brain but that by the seventh month the metabolic rate in these areas began to resemble that found in adults. Given that these areas are the ones that mediate intersensory functions (Geschwind, 1965), the current findings of no bisensory matching at 3 months of age and its emergence by the sixth month seem to provide behavioral confirmation of the physiologic findings.

There is, however, one aspect of the current data that appears to be at odds with prior data concerning bisensory response to variations in the temporal properties of stimulation. In the prior study of 4-month-old infants' bisensory response to variations in temporal frequency by Lewkowicz (1985a), no bisensory matching of temporal frequency was found. However, in contrast to the present findings, evidence for a generalized, intensity-based effect of the sound on the infants' visual fixations was found. The absence of such an intensity-based effect in the current data is puzzling, especially since the infants in this study were a month younger than were the infants in the Lewkowicz (1985a) study and, according to the Intensity Hypothesis (Turkewitz, Gardner, & Lewkowicz, 1984; Turkewitz, Lewkowicz, & Gardner, 1983), should have been even more predisposed to respond in this manner.

Data from Study 3 in the Lewkowicz (1985a) report are of greatest interest here. This was a control study designed to examine 4-month-old infants' bisensory response to variations in amount of stimulation when frequency is held constant. Durations of 50, 100, and 200 ms were used, and the results indicated that visual preferences exhibited a generalized shift in the presence of the longest auditory stimulus. Although in the current study with 3-month-old infants the durations of stimulation were actually longer and therefore presumably more intense, no such generalized shifts were found.

At first blush the current findings might seem to contradict the Intensity Hypothesis, especially if variations in duration of stimulation were the only way to produce variations in intensity. If, however, the effective intensity of a stimulus is defined in terms of neural activity, then the effective intensity of a temporally modulated stimulus must not only take into account the duration of the stimulus, but the frequency at which it is presented as well. This is because there is evidence that the visual and auditory systems each possess two separate types of cells (Cleland, Dubin, & Levick, 1971; Moller, 1969). One type, known as transient cells, respond only to the onset and offset of stimuli. The other type, known as sustained cells, respond with a sustained train of discharges which last as long as the stimulus lasts. Given the existence of these two types of cells, it would be possible to show, for example, that the effects of a 100-ms long stimulus presented twice during 1 s would not be the same as the effects of a 200-ms stimulus presented once during 1 s, even though the total length of stimulation is the same in both cases. The differential effect of these two methods of stimulus presentation would result from the fact that the 100-ms stimulus will activate the transient population of neurons twice as often as will the 200-ms stimulus, thus leading to the overall activation of a greater number of neurons.

The above hypothetical example may, in fact, help explain the discrepancy between the results from the 3-month-old group and the outcome in Study 3 in the Lewkowicz (1985a) report. The one important difference between the two studies is that the stimuli in Study 3 (Lewkowicz, 1985a) were presented at 2 Hz, a rate that was four times greater than was the rate of stimulus presentation in the current studies (0.5 Hz). Moreover, even though in both Study 2 and Study 3 of the Lewkowicz (1985a) report the duty cycle (i.e., the proportion of a single on/off cycle that the stimulus is on) of the three stimuli used was the same, in Study 2 both the 20% and the 40°% duty cycle auditory stimulus led to a general shift in visual preferences, whereas in Study 3 only the 40% duty cycle stimulus led to such a shift. The one difference between Study 2 and 3 was that the 20% duty cycle stimulus in Study 2 was presented at a rate of 4 Hz, whereas the 20% stimulus in Study 3 was presented at a rate of 2 Hz. Of particular relevance to the current data from the 3-month-old group is the fact that the duration of the 20% duty cycle auditory stimulus in Study 2 that led to a significant shift in visual preferences was actually half that of the 20% duty cycle stimulus in Study 3. Thus, when the data from the present study and the studies from the Lewkowicz (1985a) report are considered together, they appear to fit the neural effects interpretation offered earlier. Furthermore, they suggest that, as far as the infant is concerned, the effective intensity of the stimulus is not simply determined by the total amount of time the stimulus is on, but rather by a complex interaction of the duration of the stimulus and its repetition rate.

With regard to the influence of the specific nature of the stimulation on the particular kind of results obtained, one factor which might in part account for the older infants' failure to make bisensory matches on all the pairs is the "cognitive compellingness" (Warren, Welch, & McCarthy, 1981; Welch & Warren, 1980) of the stimulus situation. Welch and Warren (1980) have argued that the degree of intersensory bias observed in experiments with adults involving intersensory discrepancy may in part be accounted for by the degree to which the subject makes an assumption about whether the two sources of information represent a single or two separate events. The more the subject believes that the two sources of information represent a single event, the greater is the compellingness of the situation. According to Welch and Warren, several factors contribute to the compellingness of a situation: (a) the number and importance of various cues that provide redundant as opposed to discrepant information (these could be temporal and spatial characteristics of the stimuli); (b) the subject's general and specific history with cue redundancies and/or discrepancies in like situations; and (c) specific instructions or other situational factors.

When considered in terms of the "intersensory discrepancy" model, the experimental procedures used in the present studies may be regarded as testing the degree to which a spatially discrepant auditory stimulus can capture the infant's attention for one member of a pair of visual stimuli where one of these stimuli bears a temporal relationship to the sound. Alternatively, the procedures may be viewed as testing visual capture of auditory localization. In terms of visual capture of auditory localization, the present data indicate that by 6 months of age, infants exhibit rather impressive capture effects. On the other hand, when viewed in terms of auditory capture of visual responsiveness, the finding of any bisensory matching in the two older groups of infants is actually rather impressive. This is because the typical finding in adults is that the auditory capture of visual responding is either much weaker than the visual capture of auditory information or is nonexistent (Pick, Warren, & Hay, 1969; Warren & Pick, 1970). Regardless of the direction of capture, the fact that matching was found despite the lack of any spatially dynamic visual cues, and the fact that infants probably rarely, if ever, have the experience of seeing spatially static flashing lights and listening to beeping sounds, attest further to the impressive nature of this behavior.

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