Developmental Psychology
1985, Vol. 21, No. 2, 306–317

0012-1649/85/$00.75

Bisensory Response to Temporal Frequency in 4-Month-Old Infants

David J. Lewkowicz
Institute for the Study of Developmental Disabilities and University of Illinois, Chicago

To investigate detection of auditory–visual equivalence of rate, in the first two studies 4-month-old infants were shown pairs of check patterns flashing at 2, 4, and 8 Hz either in silence or while listening to a tone corresponding in rate to one member of the pair. In Study 1, rate of stimulation varied, whereas duty cycle (i.e., intensity) was kept constant. No evidence of bisensory matching of rate was found. In Study 2, rate and duty cycle covaried. Although no matching was found, the presence of the two most intense sounds led to a shift in looking toward lower rates of visual stimulation. In Study 3, rate was kept constant (2 Hz), whereas duty cycle was varied. No matching was found but, as in Study 2, the presence of the most intense sound led to a shift in looking toward the less intense visual stimuli. Although these findings are contrary to previous reports of auditory–visual matching of rate, they do indicate that sound influences visual preferences via an intensity-based response mechanism.

A great deal of the stimulation available to an observer is multisensory in nature. Quite often, the stimulation that impinges on the different sensory modalities may be related by virtue of some common property such as rate, rhythm, duration, shape, location, intensity, or some combination of these. The ability to detect these common properties allows us to derive higher level invariants that are no longer specific to any single modality. In general, our ability to detect intersensory relationships reflects the general integrative activity of the central nervous system and forms the foundation upon which many of our higher level perceptual, cognitive, and linguistic functions are based. In fact, some have considered the degree to which an organism is able to integrate inputs from different modalities as a criterion for evaluating the organism's psychological standing when compared with other species (Maier & Schneirla, 1964).

Although questions regarding the development of intersensory abilities have played a prominent role in discussions of the development of perception (Bower, 1977; Piaget, 1952), only recently have investigators begun to probe the infant's intersensory abilities. A good deal of attention has been devoted to the study of the infant's ability to use temporal variations in stimulation to detect intersensory relationships. In general, the evidence indicates that infants 4 months of age and older detect the equivalence of temporally varying auditory and visual stimuli either when they are presented at different times (Allen, Walker, Symonds, & Marcell, 1977; Mendelson & Ferland, 1982) or when they are presented concurrently (Humphrey, Tees, & Werker, 1979; Spelke, 1976, 1979).

With regard to temporal frequency, Spelke (1976, 1979) has shown that infants are able to use temporal frequency to detect bisensory equivalence. In those studies, infants viewed pairs of films depicting different objects moving at one of two rates while listening to a centrally presented sound. The rate of sound presentation corresponded to the rate of movement of one of the two objects. Results indicated that more infants looked toward the visual event whose rate of movement

---

I owe a special debt of gratitude to Deborah Holmes and Jill Nagy Reich for their generosity with space and equipment and to George Dombrowski for invaluable technical assistance. I am also indebted to Deborah Holmes, Jill Nagy Reich, Michael Nelson, and Gerald Turkewitz for their helpful comments on the manuscript.

Requests for reprints should be sent to David J. Lewkowicz, Institute for the Study of Developmental Disabilities, 1640 W. Roosevelt Road, Chicago, Illinois 60608.

corresponded to the rate of sound presentation.

Although Spelke's studies have provided important information about 4-month-old infants' ability to detect auditory–visual equivalence of rate, they have left a number of questions unanswered. First, it is not clear whether the velocity of each up–down movement of the visual objects was the same or different at the two rates used. From the description provided, it would seem that it was the same, in which case there would be an overall difference in the amount of stimulation across the two rates. Second, it is not clear what role the infant's differential preference for different frequencies of stimulation plays in intersensory functioning. Karmel, Lester, McCarvill, Brown, and Hofmann (1977) found that when 3-month-old infants were presented with temporally varying visual stimulation ranging in rate from 1 to 20 Hz, they showed a maximal preference for a 5.6-Hz stimulus. Because Spelke used only two different frequencies of stimulation that were lower than those found by Karmel et al. to be maximally attention-getting, it is difficult to determine whether and how differential preferences may have affected responsiveness. Finally, it is unclear how generalizable Spelke's results are. In her studies temporal variations of visual stimulation were produced by moving a continuously visible object through space. There is, however, a second way in which temporal changes may be produced; the onset and offset characteristics of a spatially static stimulus may be varied to produce different temporal frequencies.

In general, studies of responsiveness to variations in temporal frequency must take into account the way in which temporal frequency is modulated. There are two different ways in which this may be done. One is to use a stimulus of a given duration and simply to vary its repetition rate over a unit of time. The problem with this method, however, is that the total amount of stimulation presented over that unit of time increases as temporal frequency increases. It is possible, of course, to equate stimulus intensity across different frequencies by having equal "on" and "off" stimulus durations at each frequency, respectively. However, the problem with this method is that although it permits the equation of intensity, the duration of the individual stimulus making up a train of stimulation of a given frequency varies across different frequencies. The only way to disentangle the contribution that each of these attributes makes to responsiveness is to carry out systematic studies of responsiveness to different combinations of these attributes. To date, no such studies have been done with infants. In light of evidence indicating that young infants attend primarily to the quantitative attributes of stimulation (Turkewitz, Lewkowicz, & Gardner, 1983), such systematic studies take on added significance because it is possible that what appears to be a response to frequency may in fact be a response to one of the other attributes. For example, in a recent study we (Gardner, Lewkowicz, & Rose, 1983) found that newborn infants do not show specific detection of intersensory or intrasensory equivalence of rate variations but rather that they respond to the overall stimulative properties of the input. Thus although familiarization with a white noise or a white light presented at a frequency of 8 Hz led to a decrease in looking at an 8 Hz light and a concomitant increase in looking at lower frequencies of visual stimulation, familiarization with 2 Hz (weaker) stimulation did not produce such a shift.

The following three studies were designed to systematically examine infants' bisensory responsiveness to temporally modulated stimulation by varying frequency while keeping intensity constant (Study 1), by varying both frequency and intensity together (Study 2), and by varying intensity while keeping temporal frequency constant (Study 3). In contrast to prior work, in the present studies higher frequencies and a greater range of frequencies were used, baseline preferences were obtained, and spatially static rather than spatially dynamic visual stimuli were used.

Study 1

The purpose of the first study was to determine whether 4-month-old infants are able to detect bisensory equivalence of rate. Using a paired-comparison technique, infants' visual preferences for random check patterns flashing at three different rates were studied both in the presence and absence of a sound. When present, the sound was concurrent with the visual stimuli, and its rate of presentation was the same as that of one of the two visual stimuli. To eliminate the possibility that the observed responsiveness is due to differences in the intensity of stimulation rather than to differences in frequency, intensity was kept constant across different rates. Based on prior work (Spelke, 1976, 1979), it was expected either that the infants would direct their initial gaze more often toward the visual stimulus that corresponds in rate to the auditory stimulus or that they would spend more time looking at that stimulus.

Method

Subjects. Two groups of infants were studied. In the first group, visual preferences for temporally varying visual stimuli were studied in the absence of any sound (No-Sound group). In the second group, visual preferences for the same stimuli were studied, but in the presence of a concurrent sound (Sound group). The No-Sound group consisted of 16 infants (11 boys, 5 girls). These infants ranged in age from 16 weeks and 6 days to 19 weeks and 3 days (*M* age = 18 weeks and 2 days). Three additional infants were seen but were excluded from data analysis due to fussing or crying. The Sound group consisted of 12 infants (8 boys, 4 girls). They ranged in age from 17 weeks and 6 days to 19 weeks and 3 days (*M* age = 18 weeks and 4 days). Three additional infants were seen but were excluded from data analysis for the following reasons: equipment failure, 1 infant; fussing or crying, 2 infants. All infants tested were full term, with uncomplicated perinatal histories, and were in good health at the time of testing. They were all recruited from the birth records of Evanston Hospital in Evanston, Illinois and came from middle- to upper middle-class homes.

Apparatus and stimuli. The apparatus used for testing visual preferences was modeled after Fagan (1970) and consisted of a four-sided chamber. The two side walls and the top wall were lined with beige felt; 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 random check pattern. This check pattern was a replica of the random ½-inch pattern used by Karmel (1969). Each opening measured 15 × 15 cm, and the inner edges of the openings were 23.5 cm apart. From a viewing distance of 43 cm, each pattern subtended 19°18′ of visual angle. During stimulation the luminance of the white squares was 6.4 ftl, whereas that of the black squares was approximately 0 ftl. Each check pattern was lighted from behind the diffuser by two 14-watt white fluorescent bulbs housed inside a 50 × 18 × 23 cm box. To permit an essentially instantaneous onset, these bulbs were kept "warm" by a 9 VDC current during the "off" periods. To light the bulbs, a 300 VDC current was applied to them. The infants' visual fixations were observed through a 0.64-cm peephole located in the center of the wall facing the infant, and the duration of each fixation was recorded on an Apple II+ computer. 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-in. speaker was placed beneath the central fixation display midway between the visual stimuli. The auditory stimulus was a 1000-Hz tone that 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.

A custom-built square-wave generator was used to produce different temporal frequencies. Two independent channels of the generator controlled the "on" and "off" periods of each of the two visual stimuli. One of these channels also controlled the "on" and "off" periods of the auditory stimulus. In this way, the auditory stimulus and one of the visual stimuli could be gated on and off at exactly the same time and at the same rate. Gating of the stimuli was accomplished by having the output of each channel of the generator drive a relay, which in turn controlled the onset of the stimuli. The stimuli were square-wave modulated and were presented at frequencies of 2, 4, and 8 Hz. It should be noted that these frequencies are equidistant from one another on the $\log_2$ scale.

In this study, the intensity of stimulation was equated across the three frequencies by varying the "on" time of the stimulus. Figure 1 presents the stimulus parameters used at each frequency as well as a schematic representation of the temporal distribution of the stimuli. As can be seen in Figure 1, the total stimulus "on" time over a unit of time was the same at each frequency. Although one way of expressing the intensity of stimulation is by computing the total amount of stimulation presented over a unit of time, a more convenient metric for expressing the intensity of a temporally modulated stimulus is duty cycle, defined as the proportion of time the stimulus is on relative to the total time required for completion of one cycle (a cycle consists of a single "on" and "off" phase of the stimulus). In this study a 50% duty cycle was used at each frequency.

Procedure. Testing took place in a dimly illuminated room. The ambient sound-pressure level in the room was 46 dB (re .0002 dynes/cm^2, A scale). The infant was placed in a semireclining position in a commercially available infant seat at a distance of approximately 43 cm from the stimuli. As soon as the infant fixated the colored lights in the center between the stimuli, a trial was initiated by turning the central fixation display off and turning the stimuli on. Each trial lasted 15 s.

The No-Sound group was administered a series of six trials consisting of the presentation of all possible pairs of the three temporal frequencies counterbalanced for side. To counterbalance for order effects, this series of six 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 Sound group was administered a series of 12 trials. During the first trial of this series, a given pair of visual stimuli was presented with an accompanying sound whose frequency corresponded to the frequency of one member of the visual pair. The next trial consisted of the presentation of the same pair of visual stimuli but reversed in lateral position, together with the same-frequency sound as in the preceding trial. This procedure was repeated until each rate of auditory stimulation was presented together with all visual pairs containing the corresponding rate of visual stimulation. A given rate of auditory stimulation was never presented together with a visual pair when neither member of that pair corresponded in rate to the rate of sound presentation. To control for order effects, each infant was administered these trials according to one of six orders that were generated by considering each set of the two consecutive trials involving the same visual pair as a single trial.

Data analysis. The main data analyses consist of examining the duration of visual fixation as a function of visual frequency both in the presence of a temporally modulated sound whose frequency corresponded to one of the visual frequencies as well as in its absence. To determine what effect the presence of a given rate of auditory stimulation had on infants' response to different temporal frequencies of visual stimulation, separate analyses of visual preferences were carried out at each sound frequency. Because only those visual pairs that contained one member whose frequency corresponded to the sound frequency were presented, different visual pairs contributed data at a given sound frequency. Thus for the 2-Hz sound, the 2-Hz–4-Hz and the 2-Hz–8-Hz pairs contributed data; for the 4-Hz sound, the 4-Hz–2-Hz and the 4-Hz–8-Hz pairs contributed data; and for the 8-Hz sound, the 8-Hz–2-Hz and the 8-Hz–4-Hz pairs contributed data. To provide appropriate baseline data, the same pairs contributing data to the preference function in the presence of a given rate of sound presentation were used to generate the preference function in the absence of sound. Because the visual stimulus corresponding to a given auditory rate always appeared twice as often as did the noncorresponding one, the data for the corresponding visual stimulus were divided by two. It should be noted that because different sets of pairs contributed to the preference functions at each frequency of auditory stimulation, direct comparisons of these preference functions are not possible.

Results

Figure 2 shows the visual preference functions for each of the sound conditions and the corresponding functions for the No-Sound trials. As can be seen in Figure 2, there was no evidence of bisensory matching of the rate

Rate (Hz)	On Time (msec.)	Off Time (msec.)	Duty Cycle (%)
8	62.5	62.5	50
4	125	125	50
2	250	250	50
8	50	75	40
4	50	200	20
2	50	450	10
2	200	300	40
2	100	400	20
2	50	450	10

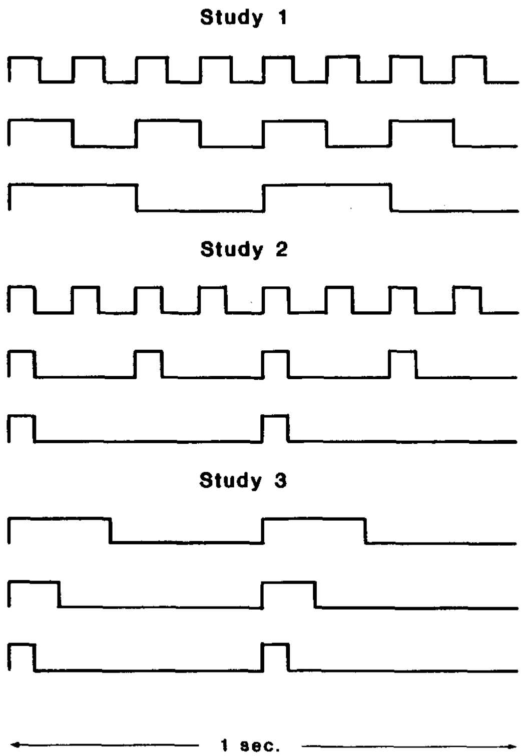

Figure 1. Schematic representation of the temporal distribution of stimuli in Studies 1, 2, and 3.

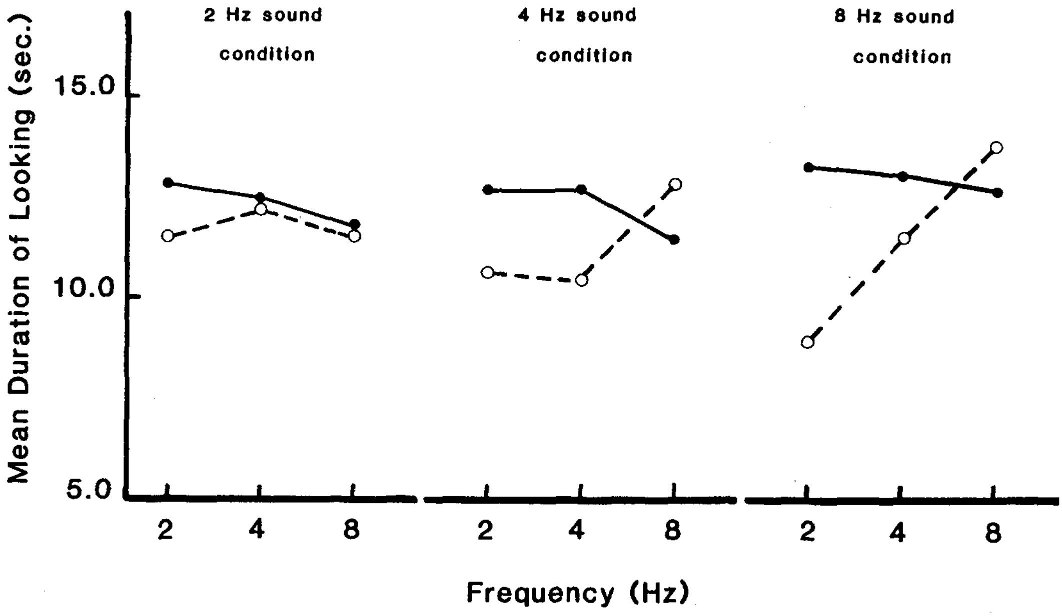

Figure 2. Mean duration of looking as a function of temporal frequency in Study 1. (Solid line represents looking during silence; dashed line represents looking during concomitant sound presentation.)

of the sound with that of the light. That is, for each sound frequency, respectively, the duration of looking at a visual stimulus flashing at a rate corresponding to the rate of the concurrent sound did not appear to be greater than the duration of looking to either of the other two rates of visual stimulation. Specifically, if infants were making auditory–visual matches of rate, then for the 2-Hz auditory condition, looking should be maximal at 2 Hz and decrease monotonically with increasing rate; in the 4-Hz auditory condition, an inverted U-shaped function, with a maximum at the 4-Hz visual stimulus, would be expected; and in the 8-Hz auditory condition, a monotonically increasing function, with a maximum at the 8-Hz visual stimulus, would be expected. A separate repeated measures analysis of variance (ANOVA), with an analysis for orthogonal components of trend, was performed on the data at each sound frequency, with visual rate as the repeated factor. No main effects of rate were significant at any of the sound frequencies. Analyses of trend indicated no significant trends at the 2-Hz sound condition, a significant linear trend, $F(1, 11) = 5.59$, $p < .05$, at the 4-Hz sound condition, and a marginally significant linear trend, $F(1, 11) = 4.28$, $p < .10$, at the 8-Hz sound condition. Thus these analyses provide no systematic evidence in support of bisensory matching. Although the data for the 8-Hz sound condition do suggest matching, the fact that the functions for the other two sound conditions are not in accord with predictions makes the case for matching untenable.

Because the measure yielding the most consistent and strongest evidence of bisensory matching of rate in prior studies (Spelke, 1979) has been the direction of initial eye gaze following the onset of sound, the data from this study were also analyzed for direction of first look. Neither analyses of initial direction of gaze for each unique pair nor for all pairs combined revealed any systematic evidence for greater turning toward the visual stimulus corresponding in rate to the auditory stimulus. Out of a total of 144 trials on which sound accompanied visual stimulation, 77 turns were directed toward the corresponding visual stimulus, and 67 turns were directed toward the noncorresponding one.

Although none of the foregoing analyses provided any evidence of bisensory matching, a comparison of visual preferences in each auditory condition and its corresponding No-Sound condition, respectively, did indicate that the presence of sound exerted an effect on the infants' visual preferences. As can be seen in Figure 2, when compared with the No-Sound condition, the effect of the 8-Hz and the 4-Hz sounds was to reduce looking toward the slowest visual stimulus and to slightly increase looking toward the fastest visual stimulus. A repeated-measures ANOVA, with rate as the within-subjects factor and group as the between-subjects factor, indicated that in the presence of the 8-Hz sound, there was a significant Visual Rate × Group interaction, $F(2, 52) = 3.61$, $p < .05$, which was mainly due to a significant interaction between the linear trends of visual rate in the two groups, $F(1, 26) = 6.45$, $p < .025$. There was also a marginally significant interaction between the linear trend of visual rate and group in the presence of the 4-Hz sound, $F(1, 26) = 4.15$, $p < .06$. There were no differences in looking when the data from the 2-Hz sound condition were compared with the No-Sound trials.

Discussion

The results of this study did not provide any evidence of bisensory matching of rate. When only the data from the Sound trials were considered, neither duration of looking nor direction of initial eye gaze were related in any systematic way to the frequency of the sound accompanying the visual stimuli.

Comparison of the data from each sound condition and its corresponding No-Sound trials did, however, suggest that sound had an effect on visual preferences. In the presence of the two fastest sounds, looking to the two slowest stimuli decreased, whereas that to the fastest stimulus increased. This effect was most pronounced in the presence of the fastest sound. Taken together, these data suggest that 4-month-old infants may be at a transition point in development. Although they do not as yet exhibit evidence of precise matching of auditory and visual rate, the presence of different rates of concurrent sound appeared to have a differential effect on their looking behavior. What is particularly important about this effect is its direction. It is in the presence of the fastest sound frequency that the clearest differentiation of looking occurred, with looking being longest toward the 8-Hz visual stimulus. However, when all the data are considered, it is clear that these effects are at variance with prior reports of bisensory response to rate in that no clearcut evidence of matching was found.

Study 2

One reason why no evidence of bisensory matching was obtained in Study 1 may be because the intensity of stimulation was equated across different rates. This was not the case in earlier studies reporting auditory–visual matching of rate. For example, in Spelke's (1976, 1979) studies the duration of stimulation was constant, whereas the interval between stimuli varied for the two rates that were used. As a result, the two rates used in those studies also had different duty cycles. Because of this, both intensity and rate varied concurrently, and it is not clear which attribute was responsible for the results obtained. It is possible, therefore, that either differences in intensity, together with rate variations, or that differences in intensity of stimulation alone, are the basis for the detection of bisensory equivalence at this age. To determine if this is in fact the case, in Study 2, the same three rates of stimulation that were used in Study 1 were used again. However, in contrast to the first study, the duration of the stimulus during its "on" portion of the cycle was constant across the three rates. As a result, differences in rate were accompanied by differences in intensity.

Method

Subjects. There were 15 infants (6 boys and 9 girls) ranging in age from 17 weeks and 4 days to 19 weeks and 3 days (M age = 18 weeks and 3 days). An additional 8 infants were seen but were excluded from data analysis for the following reasons: equipment failure, 2 infants; experimenter error, 1 infant; fussing or crying, 5 infants.

Apparatus and stimuli. In this study the duration of the "on" portion of the cycle was 50 ms for all three frequencies, whereas the duration of the "off" period varied. As a result, the duty cycle (i.e., intensity) varied with variations in frequency. Figure 1 presents the stimulus parameters used in this study as well as a schematic representation of the temporal distribution of stimulation used in this study.

Procedure. The testing procedures were identical to those employed in Study 1 except that the same infants were tested in both No-Sound and Sound conditions. As a result, each infant was administered a series of 18 trials. The first 6 trials consisted of the presentation of all possible pairs of the three temporal frequencies (counterbalanced for side) without an accompanying sound. As in Study 1, these trials were presented according to one of six orders arranged such that no given stimulus followed itself on the same side. The remaining 12 trials were presented according to the same restrictions used in the first study.

Results

As can be seen in Figure 3, there was no evidence of bisensory matching. Duration of looking at the visual stimulus corresponding in rate to the auditory stimulus was not greater than was duration of looking to the other two visual stimuli that did not correspond in rate. Analyses indicated that the main effect of rate was significant for the 2-Hz sound condition, $F(2, 28) = 11.62$, $p < .001$, and for the 8-Hz sound condition, $F(2, 28) = 6.62$, $p < .005$, and was marginally significant for the 4-Hz sound condition, $F(2, 28) = 2.81$, $p < .10$. Further confirmation of the absence of any matching was the fact that at each sound frequency, the only significant effects that were obtained were significant linear effects for rate: for the 2-Hz sound condition, $F(1, 14) = 24.96$, $p < .001$; for the 4-Hz sound condition, $F(1, 14) = 5.28$, $p < .05$; and for the 8-Hz sound condition, $F(1, 14) = 17.55$, $p < .001$.

Analysis of the direction of initial gaze once again did not yield any evidence of greater eye turning toward the corresponding visual stimulus. Out of a total of 180 trials, the infants made 95 initial eye turns toward the corresponding visual stimulus and 85 turns toward the noncorresponding visual stimulus.

Although no evidence of matching was found, comparison of the visual preference function in each sound condition and its corresponding No-Sound condition indicated that the presence of both the 4-Hz and the 8-Hz sound resulted in a change in the slope of the function. In contrast to the change observed in the first study, however, the presence of both the 4-Hz and the 8-Hz sounds resulted in a reduction in looking at the fastest frequency and a concomitant increase in looking at the slowest frequency. A repeated-measures ANOVA comparing the function for each sound frequency and its corresponding No-Sound function indicated that

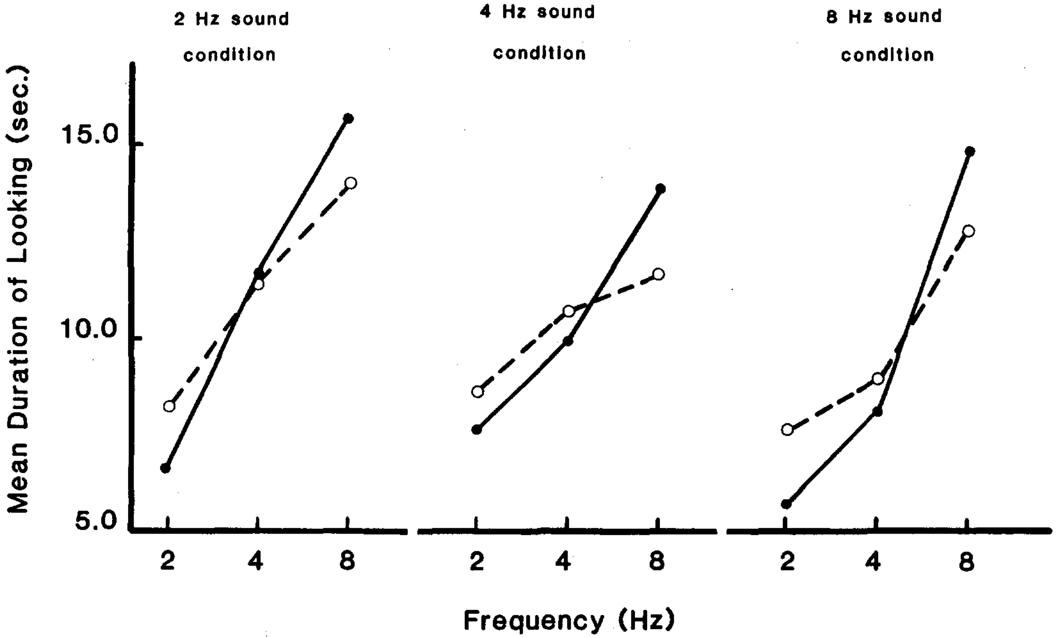

Figure 3. Mean duration of looking as a function of temporal frequency in Study 2. (Solid line represents looking during silence; dashed line represents looking during concomitant sound presentation.)

there was a significant interaction between the linear trends of rate and sound condition in both the 4-Hz, $F(1, 14) = 4.82$, $p < .05$, and the 8-Hz, $F(1, 14) = 5.05$, $p < .05$, sound conditions. The presence of the 2-Hz sound did not have any effect.

Discussion

As in Study 1, no evidence of bisensory matching of rate was found. Nonetheless, there was clearcut evidence that the presence of both the 4-Hz and the 8-Hz sound during the visual preference test led to a reduction in looking at the fastest frequency and a concomitant increase in looking at the slowest frequency.

The results obtained in this study can best be understood in the context of a view that postulates that responsiveness in young infants is based on the intensity of stimulation (Turkewitz, Lewkowicz, & Gardner, 1983). According to this view, the infant has some level of sensory input that he or she prefers. This level of stimulus intensity may be determined by the summation of intrasensory or intersensory inputs or any combination of the two.

If visual preferences are based on the intensity of sensory input, which is the result of the summation of inputs from different sources, then it should be possible to modify these preferences by introducing additional stimulation. Given a range of stimuli varying along some quantitative dimension, the introduction of additional stimulation from another source should make the whole range effectively more intense. If the original preferences are based upon the operation of a mechanism seeking to maintain some optimal level of sensory input, then raising the effective intensity of all the stimuli in the range should lead to a shift in preferences in order to preserve the same levels of effective input. This shift should be in the direction of the lower levels of stimulation.

Because, in this study, stimulus duration was constant across the three different rates, variations in the frequency of stimulus presentation introduced concomitant variations in the amount of stimulation presented over time. Thus both visual and auditory stimuli were increasingly more intense with increases in rate. According to the view outlined above, the introduction of sound should have a differential effect on preferences. That is, addition of sound should lead to a reduction in looking at the most intense visual stimulus (8-Hz) and a concomitant increase in looking at the least intense (2-Hz) stimulus. Moreover, introduction of different amounts of additional stimulation should have different effects in that the most intense auditory stimulus (8-Hz) should produce the largest shift in visual preferences. The data do in fact support these predictions. The presence of both the 8-Hz and the 4-Hz sounds did lead to a significant shift in looking preferences away from the most intense and toward the least intense visual stimulus. The fact that only the two most intense auditory stimuli led to this shift is also consistent with predictions.

Finally, an interesting question regarding the determinants of responsiveness arises when the data from both studies are considered together. In Study 1, different rates of visual stimulation elicited equal amounts of attention when presented in the absence of auditory stimulation. In contrast, in Study 2 the same rates of visual stimulation elicited increasingly greater amounts of attention as rate increased. Moreover, the presence of sound in the first study led to a differentiation of visual attention in the 4-Hz and the 8-Hz conditions by reducing looking at the lowest frequencies and slightly increasing looking toward the fastest frequency. In this study, however, the presence of these same frequency sounds led to the opposite pattern of results. This indicates that rate variations in themselves are not sufficient to elicit differential visual attention. Rather, these results suggest that it is only when rate variations are combined with intensity variations or with a temporally varying sound that differential patterns of attention emerge. What is not clear, however, is whether rate variations must be present in conjunction with intensity variations to produce differential responding or whether intensity variations per se are responsible for this effect.

Study 3

The purpose of this study was to further assess the contribution that intensity and rate variations make to responsiveness. Therefore, rate was kept constant at 2 Hz, and only intensity was varied. This was accomplished by varying duty cycle. To permit comparisons, the duty cycles chosen were equal to those used in Study 2.

Method

Subjects. There were 12 infants (7 boys and 5 girls) ranging in age from 17 weeks and 6 days to 19 weeks and 5 days (*M* age = 18 weeks and 2 days). An additional 8 infants were seen but were excluded from data analysis due to fussing or crying.

Apparatus and stimuli. Both apparatus and stimuli were the same as in the prior two studies, except that rate of stimulus presentation was kept constant at 2 Hz and duty cycle was varied to produce three different levels of intensity. The lowest intensity stimulus had a 10% duty cycle, the intermediate one had a 20% duty cycle, and the high-intensity stimulus had a 40% duty cycle. Note that these duty cycles are the same as those used in Study 2 and correspond to the 2-Hz, 4-Hz, and 8-Hz stimuli, respectively. In addition, it should be noted that these stimuli are equidistant from one another on the $\log_2$ scale. In terms of on–off durations, the 10% duty cycle stimulus was on for 50 ms and off for 450 ms; the 20% duty cycle stimulus was on for 100 ms and off for 400 ms; and the 40% duty cycle stimulus was on for 200 ms and off for 300 ms. Figure 1 depicts the stimulus parameters used in this study.

Procedure. The procedure was identical to the one used in Study 2.

Results

As can be seen in Figure 4, there was no evidence of bisensory matching of duty cycle. That is, duration of looking at the visual stimulus corresponding in duty cycle to that of the sound was not greater than duration of looking at the stimulus presented at noncorresponding duty cycles. Analyses of the data for each sound condition indicated significant effects only in the 10% duty cycle sound condition. In this condition the main effect of duty cycle, $F(2, 22) = 7.63, p < .01$, as well as the linear, $F(1, 11) = 8.10, p < .025$, and quadratic, $F(1, 11), = 5.64, p < .05$, trends were significant. Measures of first look also did not indicate any matching. The infants made 66 first looks to the corresponding visual stimulus and 78 first looks to the noncorresponding stimulus.

When the effect of concurrent sound was compared with its absence, the only significant effect was found for the 40% duty cycle sound condition. As can be seen in Figure 4, in the presence of the 40% duty cycle sound, there was a decrease in looking at the 40% duty cycle visual stimulus and a concomitant increase in looking at the 10% duty cycle stimulus. A two-way ANOVA indicated a sig-

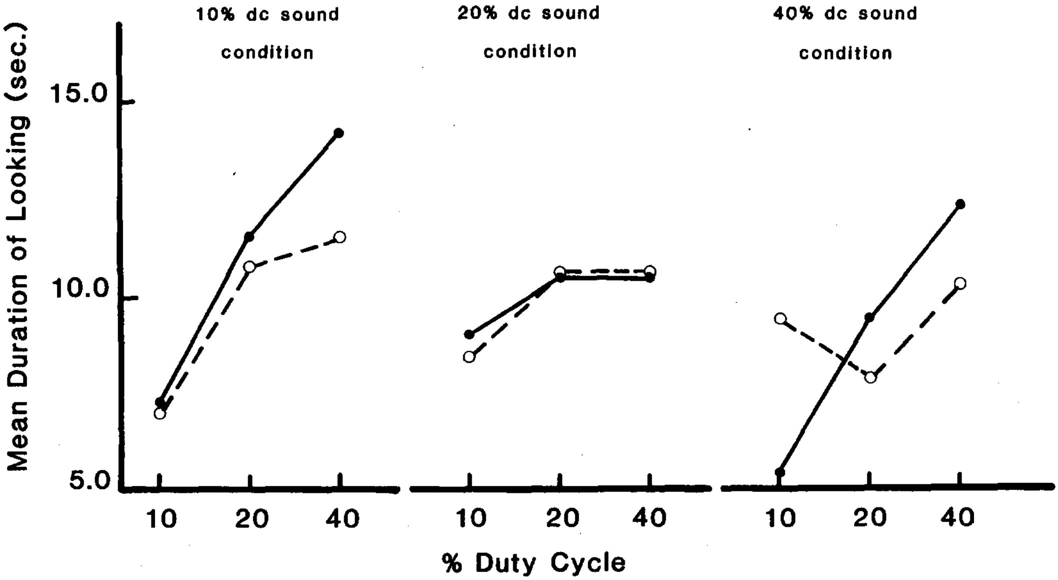

Figure 4. Mean duration of looking as a function of duty cycle in Study 3. (Solid line represents looking during silence; dashed line represents looking during concomitant sound presentation.)

nificant Sound Condition × Duty Cycle interaction, $F(2, 22) = 5.02$, $p < .025$, which was mainly due to the linear trend interaction between the Sound and No-Sound conditions, $F(1, 11) = 9.13$, $p < .025$.

Discussion

Once again, no evidence of bisensory matching was found. However, a comparison of Sound and No-Sound trials did indicate that the presence of the most intense sound caused a shift in looking patterns, with infants looking away from the most intense and toward the least intense visual stimulus. Thus the findings from this study parallel those from Study 2 and lend further support for the intensity interpretation offered earlier and are fully consistent in terms of the direction of effect. That is, as in Study 2, it was the most intense sound that had the greatest effect on visual preferences. Furthermore, these data indicate that the effects found in Study 2 are likely to be due to differences in stimulus intensity because the same kind of shift was produced in the absence of frequency variations.

A comparison of the findings from this study and those from Study 2 reveals some interesting parallels that provide further support in favor of the intensity interpretation. Both the presence of the 8-Hz sound in Study 2 and the presence of the 40% duty cycle sound in this study resulted in a shift in looking patterns relative to the No-Sound condition. This shift was characterized by a reduction in looking duration to the most intense visual stimulus and a concomitant increase in looking duration to the least intense stimulus. The presence of the 4-Hz sound had a similar effect, whereas the presence of the sound with a 20% duty cycle did not have any effect. Given that the stimuli in the two studies were identical in duty cycle, the greater effect in Study 2 suggests that rate variations in themselves may contribute to the quantitative value of the stimuli.

It should be noted that the data from the current study are also germane to another aspect of temporal processing. Because only the "on" portion of the stimulus was varied, the current study may also be considered a test of infants' bisensory response to duration of stimulation. It is clear that the data from the current study do not provide any evidence that 4-month-old infants are able to make bisensory matches of duration. However, because of the small differences in duration used here, this study should be considered a rather stringent test of this ability. It may be that with larger differences in stimulus duration, bisensory matching may emerge. Because the ability to discriminate different durations of stimulation within modalities as well as across modalities reflects basic mechanisms of central nervous system functioning, there is a need for more information concerning the development of such abilities in human infants.

General Discussion

Contrary to previous studies (Spelke, 1976, 1979) using infants of the same age, no evidence of matching of auditory and visual stimuli on the basis of temporal frequency was found in this series of studies. Neither measures of total duration of visual fixation nor of direction of initial gaze following sound presentation indicated that the infants were paying more attention to the visual stimulus that corresponded to the auditory stimulus in rate. These results cast some doubt on the generality of phenomena previously reported and suggest that whatever intersensory capacities do exist at this age, they are of a limited nature.

There are several important differences in the procedures and types of stimuli used that distinguish the current studies from Spelke's. First, the stimuli used in the present studies were pure tones and flashing checks, whereas those in Spelke's studies were films of moving puppets and sounds produced by hitting two objects together. Second, the rates used in the current studies (2, 4, and 8 Hz) were higher than those used by Spelke (0.5 and 2 Hz). Finally, the rate of visual stimulus presentation in this set of studies was controlled by varying the temporal onset and offset characteristics of *static* visual displays. By contrast, in Spelke's studies, the visual stimuli remained visible continuously, whereas their spatial position in the vertical plane changed according to one of two rates.

These procedural differences and the resulting discrepancies raise important questions regarding the necessary and sufficient conditions for demonstrating bisensory integration of temporal information in 4-month-old infants. It may be that the procedures and stimulus materials used in the two sets of studies were tapping different levels of functional organization. Thus it may be that the presence of spatially dynamic visual stimulation as well as what may be considered as ecologically more valid stimulation may be necessary for eliciting bisensory integration of temporal information at this age. If this is in fact the case, then the current findings suggest the possibility that, depending upon the nature of stimulation and the task demands, mechanisms having different levels of functional organization may be called on to mediate responsiveness.

Although the current studies failed to provide any evidence of bisensory matching of rate, there was clear evidence showing that the presence of auditory stimulation did affect the infants' visual preferences. These effects were complex and depended upon the attributes of stimulation made available to the infant. When only the rate was varied, the presence of both the 4-Hz and the 8-Hz sounds led to increased looking at the fastest stimuli. At first blush these effects might suggest some form of crude matching. In fact, when just the data from the 8-Hz sound condition are considered, they very strongly suggest the operation of a matching process. However, the fact that the presence of the 2-Hz sound did not result in greatest looking at the 2-Hz visual stimulus and that the presence of the 4-Hz sound did not result in greatest looking at the 4-Hz visual stimulus militates against such an interpretation.

The data from Studies 2 and 3 are in agreement with other studies indicating that stimulation in the auditory modality leads to a shift in responding toward lower values of visual stimulation (Gardner et al., 1983; Lawson & Turkewitz, 1980; Lewkowicz & Turkewitz, 1981). These effects have been observed both when the auditory stimulation has preceded presentation of visual stimulation (Gardner et al., 1983; Lewkowicz & Turkewitz, 1981) as well as when auditory stimulation has accompanied presentation of visual stimulation (Lawson & Turkewitz, 1980). Moreover, other work (Lewkowicz & Turkewitz, 1980) has shown that young infants can use intensity variations to make auditory–visual matches when given the opportunity to do so. It should be noted, however, that these effects have all been obtained in very young infants (less than 1 month of age). Although a number of previous studies have shown that infants as old as 4 months of age respond to the quantitative aspects of stimulation to the exclusion of such qualitative attributes as shape (Maisel & Karmel, 1978; Ruff & Turkewitz, 1975, 1979) or that quantitative factors influence responsiveness in infants younger than about 4 months of age but not in infants older than that (McCarvill & Karmel, 1976; McGuire & Turkewitz, 1978, Ruff & Turkewitz, 1975, 1979), the present results are the first demonstration that this kind of responsiveness extends to bisensory functioning in 4-month-old infants. One obvious question that arises out of these findings is whether older infants cease to respond to the quantitative aspects of the stimulation when faced with the bisensory task used here.

The finding of a shift in visual preferences in the presence of the faster and/or more intense sounds appears to be inconsistent with Spelke's findings of specific bisensory matching of rate. However, Spelke's data cannot be properly examined for the presence of such a shift because visual preferences in the absence of sound were not obtained and because lower frequencies of both visual and auditory stimulation were used. The current data indicate that only faster and/or more intense sounds presented together with faster visual stimuli produce the shift found here.

Finally, it is interesting to note that, as in the current studies, Spelke also found an overall preference for the faster stimulus. However, this preference, without an independent assessment of the infants' visual preferences in the absence of sound, calls into doubt the findings from Spelke's 1979 report. Examination of the effect of each sound frequency on direction of first look in Spelke's report indicates that only the fast (2-Hz) sound produced differential effects. The presence of the 2-Hz sound led to greater turning to the faster film. However, the slow sound had no effect, as the mean number of turns was identical toward the two films in the presence of the .5-Hz sound.

In conclusion, the present findings do not support claims that 4-month-old infants are sensitive to the amodal unity of auditory–visual stimulation when the amodal property common to both forms of stimulation is rate. However, they do show that when temporal variations are the sole attribute available to different modalities, they interact with one another but that the types of interactions present are of a general nature and are based on the total amount of stimulation present.

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.

Bower, T. G. R. (1977). *A primer of infant development.* San Francisco, CA: Freeman.

Fagan, J. (1970). Memory in the infant. *Journal of Experimental Child Psychology, 9,* 217–226.

Gardner, J. M., Lewkowicz, D. J., & Rose, S. A. (1983). *Effects of prestimulation on visual preference in neonates.* Paper presented at the meeting of the Society for Research in Child Development, Detroit, Michigan.

Humphrey, K., Tees, R. C., & Werker, J. (1979). Auditory–visual integration of temporal relations in infants. *Canadian Journal of Psychology, 33,* 347–352.

Karmel, B. Z. (1969). The effect of age, complexity, and amount of contour on pattern preferences in human infants. *Journal of Experimental Child Psychology, 7,* 339–354.

Karmel, B. Z., Lester, M. L., McCarvill, S. L., Brown, P., & Hofmann, M. J. (1977). Correlation of infants' brain and behavior response to temporal changes in visual stimulation. *Psychophysiology, 14,* 134–142.

Lawson, K., & Turkewitz, G. (1980). Intersensory function in newborns: Effect of sound on visual preferences. *Child Development, 51,* 1295–1298.

Lewkowicz, D. J., & Turkewitz, G. (1980). Cross-modal equivalence in early infancy: Auditory–visual intensity matching. *Developmental Psychology, 16,* 597–607.

Lewkowicz, D. J., & Turkewitz, G. (1981). Intersensory interaction in newborns: Modification of visual preferences following exposure to sound. *Child Development, 52,* 827–832.

Maier, N. R. F., & Schneirla, T. C. (1964). *Principles of animal psychology.* New York: Dover.

Maisel, E. B., & Karmel, B. Z. (1978). Contour density and pattern configuration in visual preferences in infants. *Infant Behavior and Development, 1,* 127–140.

McCarvill, S. L., & Karmel, B. Z. (1976). A neural activity interpretation of luminance effects on infant pattern preferences. *Journal of Experimental Child Psychology, 22,* 363–374.

McGuire, I., & Turkewitz, G. (1978). Visually elicited finger movements in infants. *Child Development, 48,* 362–370.

Mendelson, M. J., & Ferland, M. B. (1982). Auditory–visual transfer in four-month-old infants. *Child Development, 53,* 1022–1027.

Piaget, J. (1952). *The origins of intelligence in children.* New York: International Universities Press.

Ruff, H. A., & Turkewitz, G. (1975). Developmental changes in the effectiveness of stimulus intensity on infant visual attention. *Developmental Psychology, 11,* 705–710.

Ruff, H. A., & Turkewitz, G. (1979). Changing role of stimulus intensity as a determinant of infants' attention. *Perceptual and Motor Skills, 48,* 815–826.

Spelke, E. S. (1976). Infants' intermodal perception of events. *Cognitive Psychology, 8,* 553–560.

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

Turkewitz, G., Lewkowicz, D. J., & Gardner, J. (1983). Determinants of infant perception. In J. Rosenblatt, C. Beer, R. Hinde, & M. Busnel (Eds.), *Advances in the study of behavior* (pp. 39–62). New York: Academic Press.

Received November 14, 1983
Revision received March 21, 1984 ■