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Cross-Modal Equivalence in Early Infancy: Auditory- Visual Intensity Matching

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It has been proposed that young infants are attentive to quantitative variations in stimulation to the exclusion of qualitative ones. To the extent that this is so, young infants should ignore differences between lights and sounds and should instead respond to auditory and visual stimuli as more or less similar depending on their intensity. To examine this hypothesis, a cardiac habituation/dishabituation method with a test for stimulus generalization was employed. Three-week-old infants were repeatedly presented with white-light followed by white-noise stimuli of different intensities. A U-shaped relationship between magnitude of cardiac response and loudness was found. In view of previous findings that without prior visual stimulation a monotonic increase in cardiac response to the same range of auditory stimuli results, this finding of a significant quadratic relationship with loudness suggests that the infants were responding to the auditory stimuli in terms of their similarity to the previously presented visual stimulus. A separate group of infants presented with a more intense visual stimulus exhibited a shift in the intensity at which a minimal cardiac response occurred. Results of a study with adults did not show any systematic relationship between cardiac response and loudness, indicating that unlike infants, adults do not spontaneously make cross-modal matches of intensity.

Our perception of the world is based to a large extent on experiences that are multisensory in nature. There are a number of different ways in which such multisensory inputs may interact (Turkewitz & McGuire, 1978). The present article is concerned with intersensory interaction in which inputs from different modalities are responded to as equivalent. Such interaction may be based on responses to a variety of features arising from the stimulus situation. Broadly speaking, these features can be divided into those that are amodal in nature and those that are modality specific. Amodal features are those that can be used to identify an aspect of an object or an event in more than one modality, whereas modality-specific features can only be used to identify an aspect of a stimulus that is peculiar to a single modality. Thus, intensity, rate, duration, spatial location, spatial extent, rhythm, and shape all represent amodal features of the world that can be specified in more than one modality. They stand in distinction to such modality specific features of stimulation as redness, sweetness, and pitch. While modality specific features can be used to define objects (i.e., an object owes its particularity in part to the conjunction of various modality specific characteristics), amodal features can be used to abstract equivalent information under different conditions. That is, our ability to identify features of the same object haptically in the dark or visually in light is dependent on

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the equivalence of form in these different modalities.

The distinction between amodal and modality specific properties calls attention to the fact that a number of different processes are likely to be involved in intersensory relationships. Thus, whereas amodal properties may allow the detection of cross-modal equivalence, modality specific properties may permit the detection of intersensory coordination or integration but not equivalence. However, in addition to the possibility that the mechanisms underlying the detection of cross-modal equivalence are different from those underlying the detection of intersensory coordination, it is also likely that not all instances of cross-modal equivalence that are based on amodal stimulus properties are mediated by the same mechanisms. For example, the basis for the detection of cross-modal equivalence of intensity and that for the cross-modal equivalence of shape may be so different that grouping them under a common rubric may lead to confusion. In fact, a number of writers (Birch, 1962; McGuire & Turkewitz, 1979; Schneirla, 1959, 1965) have taken the position that sensory-perceptual functioning may be mediated by different mechanisms at different developmental stages and that the basis for cross-modal equivalence may therefore differ at different stages.

Schneirla (1959, 1965) has proposed that organisms initially respond to quantitative aspects of stimulation, whereas during later stages responsiveness comes to be based on the qualitative aspects of stimulation as well. According to this view, the quantitative aspects of stimulation are considered to be such stimulus features as rate of change, size, contour density, and any other variables that contribute to the overall amount of stimulation. Qualitative aspects of stimulation, on the other hand, include such modality specific attributes as color, taste, and pitch; such organizational properties as shape and melody; and finally what is perhaps the most basic, though often ignored, qualitative aspect of stimulation, the modality in which a stimulus is received. Support for Schneirla's view with regard to functioning during the early stages of development may be found in a number of studies which suggest that quantitative variables may be the salient aspect of stimulation for young infants (Fantz & Fagan, 1975; Hershenson, 1964; Hershenson, Munsinger, & Kessen, 1965; Karmel, 1969; Karmel, Lester, McCarvill, Brown, & Hofmann, 1977; McGuire & Turkewitz, 1978; Ruff & Turkewitz, 1975, 1979).

The fact that it is possible to show discrimination of stimuli varying along qualitative dimensions at early stages of development does not necessarily rule out the possibility that such discriminations are made on the basis of quantitative variations (Werner & Wooten, 1979). That is, it is almost always the case that quantitative differences accompany qualitative differences, and to demonstrate unequivocally that responding is based on the qualitative aspect of the stimuli one must first demonstrate that discrimination between qualitatively different stimuli is not affected by quantitative variations of the stimuli across a wide range (Peeples & Teller, 1975).

If young infants are indeed primarily attentive to the quantitative aspects of stimulation rather than to their qualitative aspects, it is possible that they may respond to stimuli as equivalent or not equivalent based on the degree of similarity of the stimuli with regard to their intensity. Thus, a bright light and a loud sound may be responded to as similar, whereas a bright light and a dim light may be responded to as different.

To examine this hypothesis, infants were first repeatedly presented with a visual stimulus of a constant intensity, following which they were given a generalization test involving presentation of a range of auditory stimuli varying in intensity that included an auditory intensity that was judged by adults to be equivalent to the light. It was predicted that if young infants are indeed primarily responsive to the intensity of stimulation regardless of modality, then the cardiac response during the generalization test should describe a U-shaped function. Prior studies have shown that, in the absence of visual stimulation, presentation of increasingly intense auditory stimuli results in a monotonic increase in cardiac response

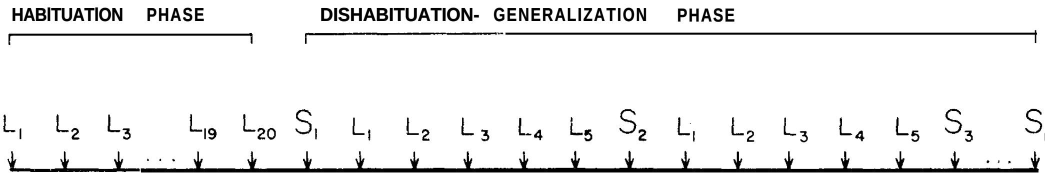

Figure 1. Schematic representation of the temporal distribution of stimuli during the testing session in Experiments 1, 2, 3 and 4. (L = light; S = sound.)

(Bartoshuk, 1964; Steinschneider, Lipton, & Richmond, 1966; Turkewitz, Moreau, Birch, & Davis, 1971). Therefore, the finding of such a U-shaped function would suggest that the different auditory intensities were not merely responded to in terms of their intensity but rather in terms of their degree of similarity to the previously experienced light.

Experiment 1

Method

Design. Cross-modal equivalence was assessed by way of a habituation/dishabituation technique with a generalization procedure included in the dishabituation phase. As may be seen in Figure 1, during the habituation phase infants were exposed to a series of 20 lights. Following the habituation phase, dishabituation-generalization testing began with the presentation of the first of a series of sounds. An additional 5 lights were then presented followed by a second sound. This sequence of a sound followed by 5 lights was repeated until all sounds were presented. The order of presentation of the sounds was random except for the requirement that across subjects each of the seven intensities be presented first approximately an equal number of times. Each visual and auditory stimulus presentation was considered a trial.

Subjects. The names of all subjects were obtained from the birth records of the Albert Einstein College Hospital. Infants were selected for the study if they had a l-minute Apgar score of 8 or higher and a 5-minute score of 9 or higher. To obtain 28 subjects for this study, a total of 69 infants were tested. There were I6 males and 12 females who were from 21 to 31 days of age (*M* age = 25.6 days; *SD* = 2 days). The remaining 41 infants were not included due to equipment failure or experimenter error (eleven infants), crying (twenty-two infants), unscorable data (three infants), refusal to accept the pacifier (two infants), falling asleep during the test session (two infants), and hiccups (one infant). Seven of these infants (4 males, 3 females, *M* age = 25.6 days, *SD* = 2.9 days), who did not complete the entire session due to crying, contributed partial data.

Apparatus. Testing took place in a sound-attenuated chamber that was dimly illuminated by an incandescent bulb (7.5 W). The overall illumination in the room was approximately .03 FC. The auditory stimuli were bursts of white noise presented through an 8-ohm speaker (Realistic MC-500) placed 64.8 cm above the supine infant. The visual stimulus was a circular patch of white light subtending 9° 24 minutes of visual angle placed 64.8 cm above the supine infant. The luminance of the light was constant at 11.4 ftL. (39.04 cd/m^2) as measured with a Spectra Pritchard Photometer. All stimulus-generating equipment was located outside the chamber. The ambient sound pressure level at the site of the infant's head was 66 dB (SPL, linear scale). All sound intensities were measured with a Bruel & Kjaer sound-level meter.

Broadband white noise (50-10000 Hz) was produced by a Grason-Stadler (Model 901B) noise generator. A Hewlett-Packard attenuator was used to vary the noise intensity. To circumvent the problem of an impedance mismatch between the attenuator and the speaker, an amplifier (Southwest Technical Tiger 01) was inserted between the output of the attenuator and the speaker.

The white light was produced by two 14-W (15-inch) General Electric Deluxe Cool (F14T12, color temperature 4200°K) white fluorescent lamps mounted inside a 52 x 39 x 32 cm wooden box. The box was painted glossy white inside to permit maximum reflectance and flat black on the outside. The front pane! of the box contained a circular opening 10.5 cm in diameter with ground glass inserted in it to provide a homogeneous field of white light. To permit the instantaneous onset of the lamps during stimulus presentation, the lamps were kept "warm" by supplying a constant 9-V direct current (DC) charge to them. As a result, during the interstimulus interval a faint reddish glow could be seen. The two lamps were connected in parallel and together drew a current of 3.8 mA from a 300-V DC power supply. A Lafayette automatic timer was used to control stimulus onset and duration.

The infants' cardiac signal was fed through a Tektronix Series 122 preamplifier (high frequency response filter set at 50 Hz, low frequency, at .8 Hz) directly to an Ampex tape recorder. For scoring purposes, a paper record of the test session was obtained by playing the tape back through a Beckman (Type R) dynograph running at a speed of 25 mm/sec.

Procedure. Infants were dark adapted for approximately 2-3 minutes. During that time, Beckman Biopotential minature electrodes were attached in a three-electrode chest configuration. The infants were placed in the supine position in a padded basinette. To insure that they looked at the light and to minimize lateral movements, their head was placed in a padded U-shaped cradle. Despite the use of the head-holding cradle, the infant's head did not always remain in the midline, and as a result it was necessary for the experimenter occasionally to reposition the infant's head between trials.

Both visual and auditory stimuli were presented for 1 sec. All interstimulus intervals were 20 sec. To provide auditory stimuli that might be equivalent in intensity to the preselected visual stimulus, two studies of cross-modal matching were carried out in adults. In view of marked differences between infants and adults with regard to both auditory and visual thresholds, as well as processing differences, it was not our aim to make direct comparisons between adults and infants but rather to have the adults provide a ballpark figure for selecting a range of auditory stimuli that might include a stimulus equivalent in intensity to the light. To this end, we employed a two-step cross-modal matching procedure (Stevens & Marks, 1965) with two groups of 14 adults in each step. The first involved the method of adjustment. Subjects were asked to adjust the intensity of a white noise until it seemed equal to the intensity of the light. The average matched obtained in that study (74 dB) was then used together with three intensities below and three above it, spaced at 2-dB intervals, in a cross-modal matching study employing the method of constant stimuli. The 74-dB sound was again found to be the best match with the light. The infants were therefore tested with auditory stimuli ranging in intensity above and below this value. Data from the lowest intensity stimulus (68 dB) are not included in any of the analyses because there is reason to believe that this stimulus was below the infants' threshold for cardiac responses. First, the 68-dB stimulus was only 2 dB above the ambient level and the level of response (6.7 beats/min) was considerably below that to the 70-db stimulus (10.2 beats/min). Second, a prior study (Turkewitz et al., 1971) found that stimuli below this intensity were below the infants' threshold for cardiac response.

The entire session lasted approximately 20 minutes.

The state of the infant was rated by the experimenter using a modification of the Prechtl (1965) scale. The following criteria were used: State 1-eyes closed, no movement; State 2-eyes partially open, some movement; State 3-eyes closed, movement: State 4-eyes open, some or no movement; State 5-eyes open, movement and vocalizations; and State 6-crying.

Scoring procedure. Following a procedure previously found to be maximally sensitive in detecting the infant's cardiac response to auditory stimulation (Turkewitz et al., 1971), the response was scored by comparing the mean cardiac rate during the seven beats immediately preceeding the onset of the stimulus and the mean cardiac rate for seven beats following onset of stimulation beginning with the third beat and ending with the ninth beat. As was done previously, the first two beats following stimulus onset were ommitted because the infant's cardiac response has a latency of approximately 1 set (Steinschneider et al., 1966). Six records were scored by two independent raters who had no knowledge of the intensity of the stimulus on the trial being scored. Agreement between each of these raters and the experimenter, who scored all the records, was 100% and 96.7%, respectively, where agreement was defined as being within one beat of each other. On those trials on which there were discrepancies greater than this the heart rate was rescored.

Results

Although the predominant response during the generalization test was acceleration, the data for the present set of experiments consist of the magnitude of cardiac change irrespective of direction. Because cardiac acceleration and deceleration may reflect the operation of different processes (Graham & Clifton, 1966), the data from the generalization trials were analyzed separately for those trials on which acceleration occurred. Data for trials when only deceleration occurred were not examined because of the low number of trials when this type of response was observed. Inspection of the data from trials on which only acceleration occurred revealed a pattern of results that was nearly identical to that obtained when both types of responses were considered. Therefore, all of the data are reported in terms of the absolute value of cardiac change.

Examination of results from the generalization trials indicates a striking nonmonotonic relationship between amount of cardiac change and sound intensity (Figure 2). Inspection of the figure indicates that there is a U-shaped relationship between cardiac change and sound intensity, with the smallest response at 74 dB and a rise in the magnitude of cardiac change as stimuli depart from this value in either direction. Analyses of trend indicated a significant quadratic trend, $F(1, 27) = 4.66$, $p < .05$ and no significant linear or cubic components.

It is possible that the observed systematic generalization stemmed from sequence effects due to the influence of preceding test stimuli on subsequent test stimuli. To examine this possibility, the data, including those from the additional seven babies who did not complete the entire session, were reanalyzed using only the response from the first dishabituation trial. Thus, this analysis utilized data from five different infants at each intensity. The results as presented in Figure 3 indicate that the overall shape of the function is similar to the one including all sound trials, although the lowest point is at 76 dB rather than at 74 dB. This difference suggests the possibility that limited order effects influenced the specific values in a generalization gradient but not the presence or shape of such a gradient. As was the case when the data including all trials were considered, there was a significant quadratic trend, $F(1, 24) = 4.93$, $p < .05$, and no significant cubic or linear trends.

Because these data consist of responses made while the infants were in different states, there is the possibility that they were influenced by a differential distribution of states at the different sound intensities. Analyses indicated that this was not the case. The infants spent over two thirds of their time in an awake, alert state (State 4). The proportion of trials on which the infants were in State 4 when the different intensities of sound were presented ranged between .63 and .82, with no systematic relationship between trials spent in State 4 and sound intensity. Further analyses assessing the relationship between cardiac change at a given intensity and proportion of time spent in State 4 indicated an absence of any correlation. As a final check on the influence of state, the data were analyzed considering only those trials on which the infant was in State 4. The overall shape of the function was essentially the same as that representing data from all states. No trend analyses were attempted due to the large number of cells with missing data when all trials on which the infant was not in State 4 were eliminated.

Another factor that might have influenced the response function is prestimulus heart rate. Analysis of mean prestimulus heart rate, however, indicated no differences between the different sound intensities.

The data were also analyzed separately for the two genders. Although the girls showed a consistently higher level of cardiac change, the pattern of response to the different auditory stimuli for boys and girls was strikingly similar. A two-way repeated-measures analysis of variance with gender as a between-subjects factor and intensity as a within-subject factor indicated a significant effect of gender, $F(1, 26) = 7.39$, $p < .05$, and intensity, $F(5, 130) = 2.32$, $p < .05$, but no significant interaction.

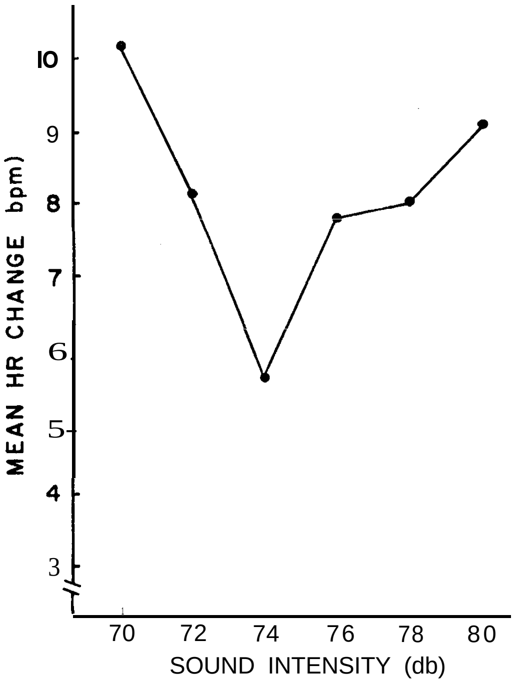

Figure 2. Relationship between cardiac response and loudness in infants exposed to a light when tested with sounds ranging from 70 to 80 dB. (HR = heart rate; bpm = beats per minute.)

Discussion

The results are in striking contrast to the pattern of cardiac responding obtained in the absence of prior exposure to visual stimuli. In the absence of such exposure, increasing the intensity of auditory stimuli, including the range used in the current investigation, results in a monotonic increase in cardiac response (Bartoshuk, 1964; Stein-Schneider et al., 1966; Turkewitz et al., 1971). Therefore, if the infants' responses to the auditory stimuli were uninfluenced by their prior exposure to the visual stimulus, the infants would be expected to respond to increasing intensities of auditory stimulation with a monotonic increase in cardiac response. If, however, the infants were

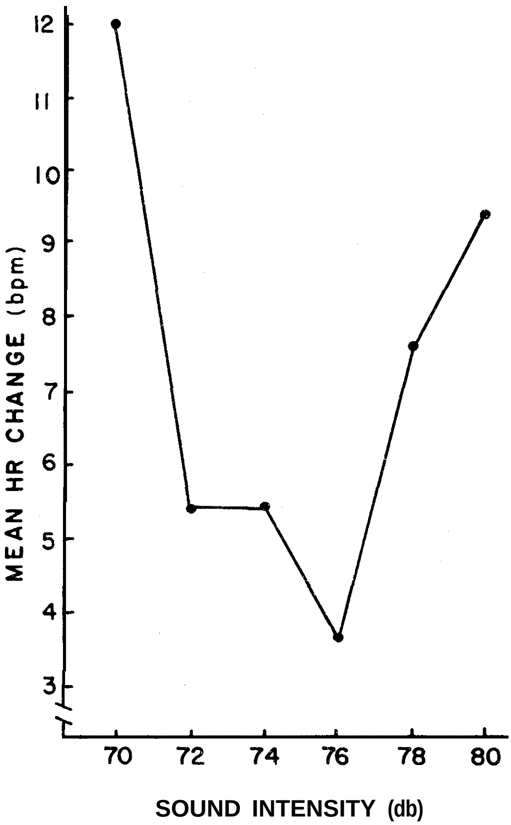

Figure 3. Relationship between cardiac response to only the first dishabituation stimulus and loudness in infants exposed to a light when tested with sounds ranging from 70 to 80 dB. (HR = heart rate; bpm = beats per minute.)

responding to the auditory stimuli in terms of their degree of equivalence to the visual stirnulus, then precisely the results obtained would be anticipated. That is, if infants were responding to the auditory and visual stimuli as similar, those stimuli that were most similar would elicit the smallest response recovery, and those less similar would elicit increasing recovery as a function of the degree of their dissimilarity to the habituating stimulus.

Although this interpretation is not dependent on the infants matching the auditory and visual stimuli in a manner comparable to that of the adults, it is nontheless of some interest that the infants matched the visual stimulus with the same-intensity auditory stimulus as did the adults.

Experiment 2

Prior studies have indicated that when instructed to do so, adults reliably and with a relatively high degree of consistency among individuals match auditory and visual stimuli on the basis of their intensity (Stevens & Marks, 1965; results of the preliminary matching studies reported here). Experiment 1 indicated that 3- to 4-week-old infants also make such matches and that, more importantly, they do so spontaneously (i.e., without training or instruction). Experiment 2 was therefore aimed at determining whether adults would also make cross-modal matches in the absence of training or instruction to do so.

Method

Subjects. The subjects for this study were 31 students from Hunter College of the City University of New York.

Apparatus and procedure. The apparatus and procedure were the same as in Experiment 1 with the following exceptions: The subjects were seated, the light source was approximately 61 cm in front of the subject and the speaker was placed approximately 70 cm above the subject's head, and the subject's electrocardiogram was recorded directly onto a Beckman Type RS dynograph.

Scoring. The method used in scoring the infant's cardiac response was also used for adults.

Results

When the data were adjusted for differences in base rate (by computing the absolute value of poststimulus rate minus prestimulus rate divided by prestimulus rate), the adults were found to make cardiac responses comparable in magnitude to those of the infants. However, examination of the magnitude of heart-rate change as a function of stimulus intensity failed to indicate a relationship between these two variables. Trend analyses failed to reveal any significant linear, quadratic, or cubic trends.

Discussion

These data suggest that adults, unlike infants, do not spontaneously equate visual and auditory stimuli in terms of their intensity. This difference between the infants and the adults must be interpreted with some caution, however, as it is quite possible that the cardiac response may not be as sensitive for adults as for infants. It should be noted, nevertheless, that cardiac responding has proven to be a reasonably sensitive measure with adults on a variety of tasks (Davis & Buchwald, 1957; Wilson, 1964). Whatever the case may prove to be with regard to the sensitivity of the cardiac measure, additional evidence that the adult does not spontaneously respond to the equivalence between auditory and visual stimuli is provided by the comments that many of the subjects in the cross-modal matching phase of the investigation made when instructed to match an auditory stimulus to the visual one. A typical response of the subjects was that the task was a bizarre one. This suggests that cross-modal intensity matching in adults does not represent the subjects' normal mode of functioning.

Experiment 3

The previous two studies indicate differences between adults and infants with regard to their cardiac response to auditory stimuli following exposure to a visual stimulus. However, the interpretation that the basis for this difference is that infants respond to an auditory stimulus in terms of its intensity-based similarity to a previously experienced visual stimulus would be greatly strengthened if exposure to a different intensity visual stimulus resulted in a shift of the point of equivalence and a corresponding shift of the entire generalization gradient. To test this possibility, a third experiment using the identical procedure but a more intense habituating stimulus was conducted. It was expected that the infants would equate the brighter light with a sound above 74 dB.

Because it was not our intention to compare the point at which adults and infants respond to an auditory and visual stimulus as equivalent, there was no need to determine the adult equivalent to the more intense light used in this experiment.

Method

Subjects. Subjects in this study were selected from the same population and on the basis of the same criteria as the infants in Experiment 1. Twenty-six infants were tested, and of these the data from 14 were usable. There were 6 males and 8 females who were from 22 to 32 days of age (*M* age = 25.7 days; *SD* = 2.6 days) at testing. Data from the remaining infants were not included due to equipment failure (1 infant), crying (8 infants), refusal to accept the pacifier (2 infants), and falling asleep (1 infant).

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiment 1 except that the luminance of the light was increased to 40.2 ftL. (137.67 cd/m^2).

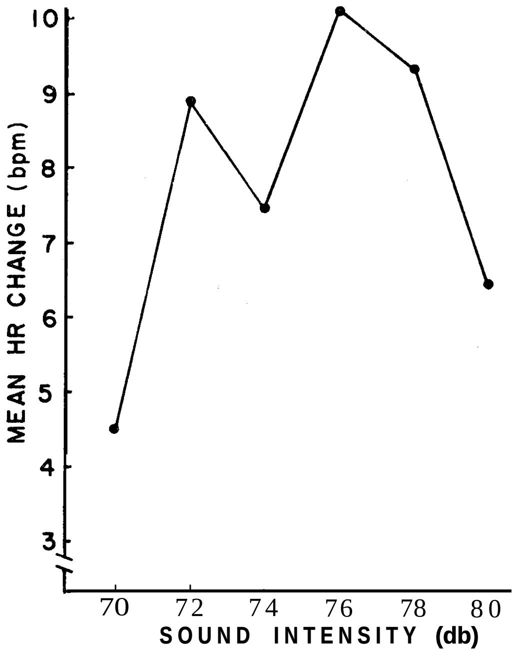

Figure 4. Relationship between cardiac response and loudness in infants exposed to a brighter light when tested with sounds ranging from 70 to 80 dB. (HR = heart rate; bpm = beats per minute.)

Results

As was the case for the infants in Experiment 1, the results from the infants in this experiment were also clearly nonmonotonic. However, inspection of Figure 4 indicates that for the infants in this experiment the relationship between stimulus intensity and cardiac change can best be described as an inverted U. Analyses indicated a significant quadratic trend, $F(1, 13) = 4.68$, $p < .05$, and no linear or cubic components.

The data were not analyzed with respect to gender or the response to the first dishabituation trial due to the limited sample size.

Discussion

Increasing the brightness of the light had a profound effect on the infants' response to auditory stimuli of the same intensity as used in Experiment 1. In view of previous findings of a monotonic increase in cardiac response with increasing intensities of white-noise stimuli (Bartoshuk, 1964; Stein-Schneider et al., 1966; Turkewitz et al., 197 l), the current findings of an anticipated decline in cardiac response at an intensity above 74 dB greatly strengthens the interpretation offered for the results previously obtained. Thus, when the infants in Experiment 1 were presented with a visual stimulus of 11.4 ftL., they responded to the 80-dB stimulus with a relatively large cardiac response, whereas those in Experiment 3 who had been exposed to the brighter light responded to the same auditory stimulus with a relatively small response. Although the decline in response at the higher intensity supports the view that the infants were responding to the degree of quantitative similarity between auditory and visual stimuli, the finding that the smallest response occurred to the 70-dB stimulus creates a problem for this interpretation. Thus, if the infants were responding to the 80-dB stimulus as most similar to the 40.2-ftL. light, a relatively large response would be anticipated to the 70-dB stimulus, since this would be maximally discrepant from the light. However, it is possible that the least intense auditory stimuli were so discrepant from the visual stimulus as to be outside the range of stimuli responded to in terms of the degree of similarity. If such were the case, the generally increasing magnitude of response obtained from 70 to 76 dB may simply reflect the infants' response to increasing intensities of stimulation similar to that observed in the absence of preceding visual stimulation.

In view of the post hoc nature of this interpretation, it was important to determine whether the responses to the more intense auditory stimuli do indeed represent one part of a generalization gradient.

Experiment 4

The interpretation offered for the results obtained in Experiment 3 suggests that had the infants been tested at intensities above 80 dB, increasing magnitudes of cardiac change would have been obtained. To test this possibility, a separate group of infants was treated in a manner identical to that of the infants in Experiment 3 except that they were tested with a range of auditory dishabituating stimuli including some that were above 80 dB.

Method

Subjects. The subjects in this experiment were from the same population and were selected on the basis of the same criteria as the infants in Experiments 1 and 3. Twenty-seven infants were tested; of these, the data from 12 were usable. There were 6 males and 6 females who were from 22 to 29 days of age (*M* age = 26.6 days; *SD* = 1.9 days) at testing. Data from the remaining infants were not included due to equipment failure (1 infant), crying (12 infants), and falling asleep (2 infants).

Apparatus and procedure. The apparatus and procedure were the same as those in Experiment 1 except that the luminance of the light was 40.2 ftL. (the same as in Experiment 3), and the range of auditory dishabituating stimuli was from 76 to 86 dB spaced in 2-dB intervals.

Results

As can be seen in Figure 5, when the infants were exposed to the brighter light and tested with sound intensities above 80 dB, they did indeed show increases in the magnitude of their cardiac response with increases in intensity of the sound. Although a trend analysis failed to reveal a significant linear or quadratic component, analysis of the data by means of a one-way repeated-measures analysis of variance indicated that the infants were in fact differentially responsive to the different intensities, $F(5, 55) = 2.58$, $p < .05$. Subsequent analyses by means of matched-pairs t tests indicated that the infants made significantly smaller cardiac responses to the 80-dB stimulus than to either the 84- or 86-dB stimulus, $t(10) = 2.60$, $p < .025$, and $t(11) = 3.24$, $p < .005$, both one-tailed, for comparison with the 84- and 86-dB stimuli. However, there were no significant differences between the magnitude of response to the 80-dB stimulus and that to the 76- or 78-dB stimuli.

It should be noted that although the anticipated increase in response to stimuli above 80 dB was obtained, the responses to the 76- and 78-dB stimuli were considerably lower than those seen in Experiment 3. Given the similarity in treatment in the two experiments, this difference is difficult to explain except in terms of individual differences. In an attempt to further explore the effect of stimulation at these intensities, we took advantage of the fact that through the first trial of the generalization phase, infants in Experiment 3 and 4 who received as their first test stimulus the 76-, 78, and 80-dB stimuli (i.e., those stimuli common to both experiments) were treated identically. Therefore, the data from four infants (two from Experiment 3 and two from Experiment 4) whose initial test stimulus was 76 dB were combined, as were the data from three infants whose initial test stimulus was 78 dB and from four whose initial stimulus was 80 dB. The mean cardiac response of these infants was 6.8, 6.6, and 1.8 beats per minute for the 76-, 78-, and 80-dB stimuli, respectively.

Discussion

Although the data for the infants in this experiment did not describe the expected U-shaped function, the prediction of greater cardiac responding to sound intensities above 80 dB was confirmed. In addition, when the data for those infants in this experiment and in Experiment 3 who were treated identically through the first test generalization trial were combined, the data revealed the increased response at the lower intensities that would be expected by the intensity-matching hypothesis. It is unclear whether the high degree of variability found between the results of Experiments 3 and 4 as regards the response to the 76- and 78-dB stimuli is a function of variability within or between infants. The presence of such variability is, however, consistent with the general findings of high levels of variability in the response of infants. Whatever the source of variation, when the data from Experiments 3 and 4 are considered jointly, they suggest a range of equivalence between the auditory and visual stimuli, with the infants finding the best match for the 40.2-ftL. light somewhere in the vicinity of 80 dB.

Habituation

Finally, to determine whether there was a decrement in response over the 20 habituation trials, the mean cardiac change for blocks of five trials was computed for every subject. Analyses of variance indicated no significant effects of trials in any of the experiments. Although we cannot explain the absence of habituation, together with clear evidence of a gradient of dishabituation, it should be noted that the finding of discriminative responding by use of the familiarization-novelty paradigm has not required a prior reduction in response to the exposed stimulus (Fagan, 1974).

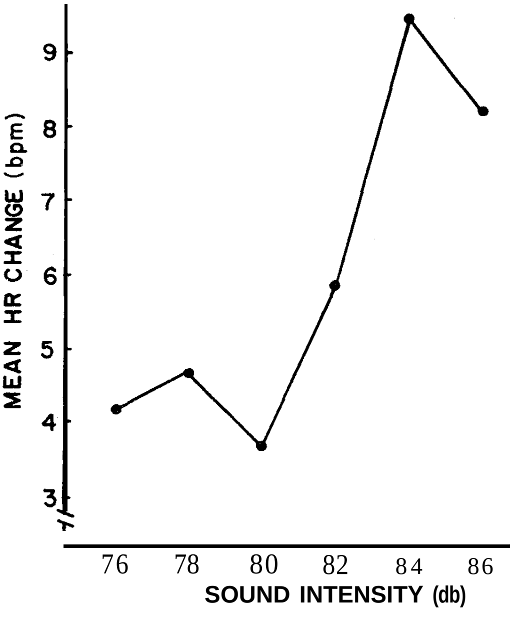

Figure 5. Relationship between cardiac response and loudness in infants exposed to a brighter light when tested with sounds ranging from 76 to 86 dB. (HR = heart rate; bpm = beats per minute.)

General Discussion

The results indicate that not only are 3- to 4-week-old infants differentially responsive to auditory stimuli of different intensities, but such differential responsiveness is markedly affected by prior exposure to stimulation in the visual modality. Thus, following exposure to a light, we found an orderly generalization gradient when the response to an auditory stimulus was smallest to an intermediate intensity and increased to intensities below as well as above it. Exposure to a higher intensity visual stimulus resulted in a shift of the generalization gradient such that there was a reduction in response to a louder sound than was the case for the group exposed to the dimmer light.

The data support the view that the response to the sounds reflects the infants' response to different degrees of similarity between the auditory and visual stimuli. This conclusion is based on the fact that in previous studies it was found that in the absence of prior visual stimulation, the relationship between increasing intensity of auditory stimulation and magnitude of heart-rate change is monotonic, whereas in the current investigation, following exposure to a light, a U-shaped generalization gradient in response to the auditory stimuli was obtained. Furthermore, some qualified evidence for a predictable shift in the generalization gradient consequent on a shift in the intensity of the visual stimulus was obtained.

The present data, therefore, provide support for Schneirla's (1959, 1965) proposal that early in development organisms respond primarily to the quantitative aspects of stimulation and extend the generality of the evidence supporting this position to include intersensory functioning. That is, they suggest that for the young infant the salient characteristics of stimulation are variations along quantitative dimensions, whereas variations along qualitative dimensions (e.g., modality) are essentially ignored. Thus, the infant responds not to the differences in the modality of stimulation but to the amount of stimulation.

In addition, the data suggest that the major distinction between the response of infants and adults to visual and auditory stimuli may not be with regard to differences in their ability but rather to differences in the dimension of stimulation spontaneously attended to. Consequently, the data are best interpreted as indicating that infants spontaneously ignore differences in the modality in which stimuli are presented and use in-, tensity to make cross-modal matches. The importance of this distinction between ability and spontaneous use is indicated by the results of the experiment carried out with the adults. Using a design and procedures identical to those used with the infants, we found that there was no systematic relationship between loudness and heart-rate change. This would suggest that unlike infants, adults do not spontaneously use intensity for making cross-modal matches even though when instructed to do so they made such matches quite reliably. We would therefore emphasize the possibility that differences between infant and adult processing of sensory information may reflect differences in the aspects of stimulation attended to rather than differences in ability.

Our approach further suggests the caveat that care be taken to distinguish between various types of cross-modal equivalence. That is, some equivalences may be based on primitive and undifferentiated functioning, whereas others may represent the highest levels of cross-modal functioning and may involve perceptual and cognitive as well as sensory mechanisms. In this sense, there is no contradiction between our finding of cross-modal equivalence in 3- to 4-week-old infants and the failure to obtain reliable evidence of cross-modal transfer of form prior to 6 months of age (Bryant, Jones, Claxton, & Perkins, 1972; Gottfried, Rose, & Bridger, 1977; Rose, Gottfried, & Bridger, 1978; Ruff & Kohler, 1978). In fact, we would expect that the formation of cross-modal equivalence of form would occur only when the infant is no longer primarily attentive to quantitative variations. For example, it has been found that although the response of younger infants (6 weeks old) to different patterns is determined primarily by quantiative variations, older infants tend to ignore these variations and attend to their qualitative variations (i.e., form characteristics; Ruff & Turkewitz, 1975, 1979). Thus, we would expect that when cross-modal equivalence of form is present, the type of intensity-based equivalence found in the present study may no longer be the infant's characteristic mode of functioning.

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