INFANT BEHAVIOR AND DEVELOPMENT 20 (3), 1997, pp. 349-357 ISSN 0163-6383

Do Infants Perceive Invariant Tempo and Rhythm in Auditory-Visual Events?

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Two experiments tested 7-month-old infants' ability to categorize events on the basis of invariant rhythm or tempo. Videotaped auditory-visual events (a hammer striking a surface to create characteristic rhythms and tempos) were presented to infants using an habituation procedure. In Experiment 1, following habituation to events depicting one tempo amid three rhythms, infants showed a significant recovery of visual attention to a change in tempo and rhythm, but not to a change in rhythm alone. In Experiment 2, following habituation to events displaying one rhythm amid three tempos, infants did not show a recovery of visual attention to a change in rhythm and tempo, nor to a change in tempo alone. The pattern of results suggested that 7-month-old infants categorized events on the basis of invariant tempo amid changing rhythms, but did not appear to do so for an invariant rhythm in the context of changing tempos.

tempo rhythm categorization

The rhythm of an event refers to the pattern of action over time, while its tempo refers to the rate of stimulation (Fraisse, 1978). Many natural events (e.g., spoken language, hands clapping, a ball bouncing) display both a characteristic rhythm and tempo. According to Gibson (1969), infants can abstract the invariant amodal structure of events, including temporal information such as rhythm and tempo. Prior studies, reviewed below, suggest that infants are fairly adept at discriminating changes in either the rhythm or tempo of a stimulus. However, many events display both rhythm and tempo, and few studies have manipulated both to test the infants' ability to perform more complex perceptual tasks. For example, will infants categorize events on the basis of a temporal invariant, that is, abstracting an invariant rhythm in the context of changes in tempo, or vice versa?

In a prior study, we observed that 7-month-olds discriminated several rhythm and tempo contrasts displayed in dynamic, bimodal videotaped events (Pickens & Bahrick, 1995). The present study extended the prior research as follows: Experiment 1 tested the 7-month-olds' ability to abstract an invariant tempo in the context of changing rhythms, while Experiment 2 tested if the infants would abstract an invariant rhythm amid changes in tempo.

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INFANTS' SENSITIVITY TO TEMPO

Studies on infants' discrimination of tempo, testing infants as young as 6 weeks old, have reported that infants look more at stimuli flashing at certain rates than at others, suggesting they can visually discriminate tempo (Balaban & Dannemiller, 1992; Freedland & Dannemiller, 1987; Karmel, Lester, McCarvill, Brown, & Hofmann, 1977). For acoustic stimuli, Trehub and Thorpe (1989) reported that 7- to 9-month-old infants discriminated changes in the tempo of 3- and 4-tone sequences. Additional evidence for infants' sensitivity to tempo comes from studies of their intersensory perception. Spelke (1979) observed that 4-month-olds looked longer at a filmed object whose motion matched the tempo of sounds. However, other researchers (using spatially static stimuli instead of filmed events) failed to observe auditory-visual matching on the basis of tempo prior to 6 months old (Humphrey & Tees, 1980; Lewkowicz, 1985; 1992; Moore & Gibbons, 1988). Lewkowicz (1988a; 1988b) observed that 6-month-olds discriminated a 2- to 4-Hz change in the tempo of a compound auditory-visual stimulus when both auditory and visual components changed tempo. By 10 months of age, infants responded to changes in the tempo of either the acoustic or visual components of the stimuli. This suggests a developmental progression, such that infants become increasingly sensitive to finer aspects of the tempo of events as they mature.

Recently, Pickens and Bahrick (1995) observed that 7-month-old infants discriminated changes in the tempo of a videotaped, auditory-visual event consisting of a hammer striking a surface. Infants were habituated to events displaying one rhythm presented at a constant tempo, followed by test trials presenting the familiar rhythm at a novel tempo. Infants showed a significant visual recovery indicating discrimination of a novel tempo (1.2 vs. 4 Hz and 1.8 vs. 2.7 Hz contrasts), with a larger recovery observed for the larger magnitude shifts in tempo. Infants' discrimination of the tempo shifts were observed across four underlying rhythm contexts.

INFANTS' SENSITIVITY TO RHYTHM

When the duration of an element or interval making up a rhythmic pattern is changed, this is referred to as an absolute timing shift. When only the order of otherwise identical elements and intervals making up a rhythm pattern is changed, this is referred to as a relative timing contrast. Researchers have demonstrated that by 1-1/2 to 3 months old infants can discriminate some absolute timing shifts in the rhythm of acoustic stimuli (Demany, McKenzie, & Vurpillot, 1977). However, it is not until later in development, between 5 and 12 months of age, that infants begin to discriminate relative timing changes in the rhythm of acoustic stimuli (Chang & Trehub, 1977; Morrongiello, 1984, 1986, 1988). For example, Morrongiello (1984) reported that while 6-month-old infants detected absolute timing shifts in a series of white-noise bursts, infants did not detect relative timing rhythm contrasts until twelve months of age.

Mendelson and Ferland (1982) reported evidence of crossmodal rhythm discrimination by 4-month-old infants. Following familiarization to a rhythm presented acoustically, the infants responded to an absolute timing change in a rhythm presented visually. In another study, Mendelson (1986) presented 4- and 8-month-old infants with films of a puppet moving up and down in relative timing rhythms characterized as low, medium, or high in complexity. Infants looked more at the medium complexity rhythm at 4 months, but looked more at the high complexity pattern at 8 months. These studies suggest that infants visually discriminate some rhythms by 4 months of age, but that the salience of different rhythms may shift with age.

Pickens and Bahrick (1995) observed that 7-month-old infants discriminated relative timing rhythm contrasts displayed by a videotaped toy hammer striking a surface along with its natural, synchronized impact sounds. Infants habituated to one rhythm presented at a constant tempo subsequently responded to a novel rhythm presented at the familiar tempo. Discrimination (indexed by a recovery of visual fixation to a novel rhythm) of four different relative timing rhythm contrasts was observed at each of four constant tempos in these bimodal events.

The prior studies suggest a developmental progression, such that younger infants have some ability to discriminate rhythms and tempos, but they come to detect finer or more subtle aspects of temporal structure later in development. Investigators have presented infants with very different types of stimuli: visual, acoustic, or multimodal; white noise vs. tones; spatially static vs. dynamic; absolute vs. relative timing shifts; larger vs. smaller tempo shifts, etc. The age when discrimination of rhythm or tempo is observed is clearly influenced by the type of stimuli presented. For example, investigators have reported rhythm discrimination at 4 months of age for absolute timing shifts presented across modalities (Mendelson & Ferland, 1982), at 7 months of age for relative timing contrasts depicted in auditory-visual events (Pickens & Bahrick, 1995) or not until 12 months old for relative timing contrasts presented acoustically (Morrongiello, 1984). Likewise, 2- to 3-month-olds discriminate some changes in the tempo of a visual stimulus (Balaban & Dannemiller, 1992), and 4-month-olds match dynamic films and sounds on the basis of tempo (Spelke, 1979). However, with spatially static stimuli, and dependent upon whether a tempo shift is presented to the auditory or visual sensory modality, infants may not detect some changes in tempo until 10 months of age (Lewkowicz, 1988a, 1988b). These prior studies generally suggest that infants' temporal discrimination skills improve with development. However, few studies have examined more complex perceptual tasks, such as the extent to which infants can categorize stimuli on the basis of a temporal invariant amid other stimulus changes.

Categorization

Categorization involves the perceiver treating discriminably different objects or events as equivalent on the basis of one or more properties (Cohen & Strauss, 1979; Cohen & Younger, 1983; Mervis & Rosch, 1981). Prior studies have shown that infants are able to form categories based on objects sharing a common physical feature (such as color or shape). Trehub and Thorpe (1989) reported that 7- to 9-month-old infants showed evidence of categorization on the basis of rhythm across variations in the tempo for 3- and 4-tone acoustic sequences. However, researchers have not yet explored the infant's categorization of multimodal events on the basis of rhythm or tempo. To this end, the present study hypothesized that 7-month-old infants would treat as equivalent stimuli displaying: (a) a common tempo amid several changes in rhythm, and (b) a common rhythm across several changes in tempo.

EXPERIMENT 1: DETECTION OF INVARIANT TEMPO

Seven-month-olds were habituated to videotaped events depicting three different rhythms at the same tempo. Following habituation, infants received test trials of either a novel-tempo/novel-rhythm or familiar-tempo/novel-rhythm, and their visual recovery to the stimuli was assessed. A significant visual recovery was expected for infants who received the novel-tempo/novel-rhythm (new category), but not those who received the familiar-tempo/novel-rhythm (another rhythm exemplar in the familiar tempo category).

METHOD

Participants

Thirty-two 7-month-old infants ($M = 215.2$ days, $SD = 6.0$) participated, with 17 boys and 15 girls. The data for 6 infants were eliminated due to crying during testing, and for 2 infants for failure to habituate (see procedure section, below, for an explanation of the rejection criteria). All participants were healthy, full-term infants with no complications during delivery and no reported health problems. Neither ethnicity nor other social, economic or demographic data were collected.

Stimuli

Events consisted of videotaped recordings of a bright red plastic hammer striking a wooden surface. The hammer was manipulated with a black wooden rod which blended with a black background so that the rod was not visible. The hammer (25 cm in length) was moved up and down (a distance of 21 cm) in a typical hammering motion, repeatedly striking the surface to create a characteristic rhythm and tempo. A programmable metronome was used to time the hammer impacts during filming, with the same velocity and trajectory of motion maintained across impacts. The natural, synchronized impact sounds were directly recorded onto videotape.

Four rhythm patterns were filmed at each of four tempos. The rhythms differed only by the relative order of impacts and intervals in each pattern (i.e., relative timing contrasts), with the number and duration of impacts the same for all rhythms. Each rhythm consisted of a repeating cycle of a 4-beat measure of 4 impacts alternating with a 4-beat measure of rests, as follows:

1. *x xx o x*,
2. *x o xx x*,
3. *x x o xx*, or
4. *xx o x x*.

where *x* represents a whole-beat impact, *xx* two half-beat impacts, and *o* a whole-beat rest.

Each pattern was filmed at each of four tempos (1.2, 1.8, 2.7 and 4.0 Hz)[1] resulting in 16 possible rhythm-tempo combinations. A control stimulus consisted of a video display of metal keys on a ring in front of a white background. The keys were intermittently shaken to produce a jingling sound.

Apparatus

Infants were seated in an infant seat surrounded by black curtains and facing a 19-in color video monitor at a distance of 55 cm. The screen was surrounded by black poster board with two small apertures cut into it to allow observers to monitor the infants. A set of colored lights and a mechanical toy dog positioned above the video monitor were used to orient the infants' attention forward at the beginning of each session.

Procedure

Infants were tested using an infant control habituation procedure (Horowitz, Paden, Bhana, & Self, 1972). Observers' recordings of all trials were initiated as soon as the infant fixated the visual display and terminated once the infant looked away for 1.5 s. Inter-trial intervals were 5 s, with 120 s set as the maximum trial length. Observer(s) recorded infants' visual fixations to the displays using buttons connected to a computerized event recorder. The computer was programmed to record fixation on line, signal when each trial was over (when the infant looked away for 1.5 s), and when the habituation criterion was met. Only the observations of a primary observer controlled the stimulus presentations, while the observations of the secondary observer were recorded to calculate inter-observer reliability. The observers could not view the monitor from their positions, and they wore headsets which produced white noise at 80 dB to mask stimulus sounds (which averaged 60–65 dB) so that the observers were not unaware of the stimulus condition.

Prior to the habituation sequence, the control display (keys) was presented. The initial control trial assessed infants' natural level of visual fixation to a moving-sounding stimulus, and provided a warm-up period for infants to acclimate to the experimental setting. This control trial stimulus was presented again at the end of the entire testing session, to assess the infants' ability to respond to a novel stimulus at the end of the session as an index of fatigue.

Following the initial control trial, each infant received the habituation series consisting of three different rhythms all presented at the same tempo. Visual fixations during the first three habituation trials were averaged by the on-line computer to arrive at a baseline of initial visual fixation. The habituation sequence consisted of 5 mandatory trials, and then continued until the habituation criterion was reached (defined as a fixation decrement of 50% or greater relative to baseline on 2 consecutive trials). Three posthabituation trials (continuing the habituation sequence) were presented after the habituation criterion was reached to establish a more conservative habituation criterion and to control for regression effects (see Bertenthal, Haith, & Campos, 1983).

Immediately following the 3 posthabituation trials, all infants were presented a series of 3 test trials to assess visual recovery. The 32 infants were randomly assigned to one of two test conditions presenting either: (a) a novel rhythm at a novel tempo (experimental), or (b) a novel rhythm at the familiar tempo (control). Order of rhythm presentation was counter-balanced across participants in each condition (there were 4 randomly selected rhythm orders: 2,4,1–3 vs. 3,1,4–2 vs. 1,3,2–4 vs. 4,2,3–1 with the first 3 rhythms presented in a rotating sequence across habituation trials, and the fourth rhythm presented on test trials). Four infants in each group were habituated at tempos of 4.0, 2.7, 1.8, and 1.2 Hz, respectively. Infants in the experimental group received tempo contrasts of 4.0–1.2 Hz, 1.2–4 Hz, 2.7–1.8 Hz, or 1.8–2.7 Hz, respectively. Infants in the control group received no change in tempo on test trials.

To ensure that infants had, in fact, habituated to the stimulus events, data for infants whose mean posthabituation fixation level exceeded that of their mean baseline fixation level were excluded from the analyses ($n = 2$ excluded on this basis). Second, to ensure that infants in the sample were not overly fatigued, their visual fixation during the final control trial (keys) was compared with that of the initial control trial. If looking on the final control trial was less than 20% of the initial fixation level that subject's data were omitted (no data were omitted on this basis in Experiment 1).

A second observer monitored visual fixations for 28% of the infants to assess inter-observer reliability. The mean Pearson product moment correlation between the two observers' trial by trial observations of looking time for each infant was calculated and averaged across infants, resulting in a correlation of .99.

Results

The performance of infants during habituation was assessed by examining the following variables: mean seconds of visual fixation on baseline, habituation criterion and posthabituation trials, as well as the number of trials and total seconds of visual fixation to reach the habituation criterion (Table 1). Analyses of variance (ANOVAs) with condition (experimental vs. control) as the main between-subjects factor were performed on each habituation variable. These analyses revealed no significant main effects of condition, $p > .10$ for all tests, indicating that experimental and control infants did not differ a priori, and so the pattern of recovery scores was not accounted for by differences in habituation across the two groups.

Difference scores were calculated as a measure of recovery of visual fixation to the test displays. Mean visual fixation for the 3 posthabituation trials was subtracted from mean visual fixation for the 3 test trials. This "recovery score" reflected the change in the amount of visual fixation to the test stimuli relative to each subject's own habituated visual fixation level. Positive recovery values indicated discrimination, while negative recovery scores indicate generalized habituation to the test stimulus. As shown in Table 1, the mean visual recovery was positive for the experimental group ($M = +2.90$ s) in contrast to the control infants, who showed a negative recovery ($M = -0.73$ s). A three-way ANOVA performed on the recovery scores with condition (2 levels), rhythm-order (4) and habituation tempo (4) as factors, produced a significant main effect of condition, $F(1, 30) = 6.92$, $p < .02$. In that analysis there were no significant main effects or two-way interactions for rhythm-order or tempo, $p > .10$, both tests (three-way interactions were not examined). Follow-up t tests revealed that the positive recovery score was significantly greater than 0 in the experimental condition, $t(15) = 10.54$, $p < .01$, but this was not the case in the control condition, $p > .10$. A total of 12 of 16 infants showed a positive recovery score in the experimental condition; in contrast, only 2 of 16 control infants did so, χ^2 (1, $N = 32$) = 12.70, $p < .05$. These results suggest that the 7-month-olds abstracted the invariant tempo across changes in rhythm, and responded to a novel tempo cate-

TABLE 1
Visual Fixation as a Function of Test Condition in Experiments 1 and 2

Test Condition		Initial Control	Final Control	Baseline	# of Trials	# of Seconds	Criterion	Post-habit.	Test Trials	Visual Recovery
EXPERIMENT 1										
New Tempo/	*M*	24.5	21.8	24.0	8.4	117.9	5.4	4.8	7.7	+2.9*
New Rhythm	*SD*	(5.4)	(6.6)	(14.0)	(3.3)	(47.5)	(2.2)	(3.0)	(3.8)	(4.3)
Old Tempo/	*M*	28.6	21.6	25.9	8.0	124.6	5.0	5.0	4.3	−0.7*
New Rhythm	*SD*	(7.3)	(4.5)	(13.4)	(1.4)	(62.2)	(3.0)	(3.5)	(3.0)	(3.0)
EXPERIMENT 2										
New Rhythm/	*M*	31.0	24.5	21.7	8.0	106.2	4.8	5.9	4.7	−1.2
New Tempo	*SD*	(4.9)	(6.1)	(9.4)	(2.1)	(35.7)	(2.3)	(2.6)	(2.9)	(3.9)
Old Rhythm/	*M*	28.5	25.5	22.5	8.8	118.5	4.7	5.1	6.5	+1.4
New Tempo	*SD*	(6.1)	(10.4)	(11.3)	(3.5)	(39.0)	(3.0)	(2.8)	(5.5)	(6.7)

Notes. Initial and Final Control Trials = visual fixation to keys. Baseline = number of seconds of fixation averaged over the first 3 habituation trials; # of Trials = number of trials to habituation criterion; Seconds = cumulative seconds of visual fixation until the habituation criterion was reached; Criterion = seconds of visual fixation averaged across 2 habituation criterion trials; Posthabit. = seconds of fixation averaged over 3 posthabituation trials; Test Trials = seconds of visual fixation averaged across 3 test trials; Visual Recovery = difference between mean Test and Posthabituation trials fixation. * indicates significantly different at the $p < .05$ level or less.

gory, but generalized habituation to a rhythm change alone.

Additional analyses were performed to assess if the visual recovery observed in the experimental group differed as a result of the magnitude (extreme vs. intermediate) shifts in tempo on test trials. Half of the experimental infants received an extreme shift in tempo from habituation to test trials (4 vs. 1.2 Hz, or 1.2 vs. 4 Hz), while the other half were presented a more intermediate change in tempo (2.7 vs. 1.8 Hz, or 1.8 vs. 2.7 Hz). Infants presented the more extreme tempo contrast showed a larger recovery ($M = +4.63$ s) than those presented the inter-mediate contrast ($M = +1.17$ s), with only the recovery to the more extreme tempo contrast significant relative to matched controls, $t(14) = 3.57$, $p < .01$, and $t(14) = 1.01$, $p > .10$, respectively. Another analysis included a two-way ANOVA on recovery scores with condition (2) and gender (2) as factors, and this revealed no significant gender effects, $p > .10$.

Discussion

Experiment 1 revealed that 7-month-old infants detected the invariant tempo in the context of changing rhythms in a series of dynamic, bimodal stimuli. When infants were habituated to a series of discriminably different rhythms presented at a single tempo, they responded to a novel rhythm presented at a novel tempo, but not to a novel rhythm presented at the familiar tempo. This suggests the infants abstracted the invariant stimulus tempo during habituation, and responded only to a novel tempo category, but did not respond to a novel rhythm, presumably because this was treated as just another exemplar from the familiar category.

EXPERIMENT 2: DETECTION OF INVARIANT RHYTHM

A second experiment was performed to examine infants' detection of invariant rhythm in the context of changing stimulus tempos. The design of Experiment 2 was similar to that of the first experiment, except that the role of tempo and rhythm was reversed. Infants were habituated to events of different tempos that displayed a common rhythm. Following habituation, test trials were presented displaying either: (a) a novel rhythm and novel tempo, or (b) a familiar rhythm at a novel tempo. It was predicted that infants would abstract the invariant rhythm during habituation and show a visual recovery to a change in rhythm but not a change in tempo.

METHOD

Participants

Thirty-two infants whose mean age was 215.4 days (SD = 5.4) participated, with 18 girls and 14 boys. They were recruited from the local community, and all were healthy with no complications during delivery. Data from additional infants were collected but rejected from analyses because they fell asleep during the procedure (n = 2), experienced equipment failure during testing (n = 2), failed to habituate (n = 2), or were excluded due to the fatigue criterion (n = 1) (see Experiment 1 procedures for a description of the rejection criteria).

Procedure

The stimulus films and apparatus were identical to those of Experiment 1. All infants again received an initial control trial (keys). Habituation consisted of a series of trials depicting the same rhythm presented at each of three tempos. Following habituation, the 32 infants were randomly assigned to one of two test conditions, (a) a novel rhythm-novel tempo, or (b) the familiar-rhythm/novel-tempo, and visual recovery was assessed. Randomly selected tempo presentation orders and rhythm contrasts were counterbalanced across participants and conditions. In the experimental (novel-rhythm/novel-tempo) condition, 4 rhythm contrasts (e.g., rhythm 1 during habituation vs. rhythm 3 during test, 3 vs. 1, 2 vs. 4, and 4 vs. 2) were counterbalanced across participants. In both conditions, stimuli displayed a different tempo on each trial, presented in 1 of 4 randomly selected tempo orders (e.g., 4.0, 1.8, 1.2 Hz, etc.) with tempo orders counter-balanced across the participants and conditions in Experiment 2.

The final control trial (keys) was again presented last and the same rejection criteria as those employed in Experiment 1 were observed. A secondary observer monitored visual fixations for 41% of the infants. The mean Pearson correlation between visual fixation recordings of the two observers, taken for each participant and then averaged across infants, was .99.

Results

A summary of the habituation variables are presented in Table 1. A series of ANOVA were performed on each habituation variable (baseline, number of trials to habituate, seconds of visual fixation until habituation, mean looking on habituation criterion trials, and posthabituation trials), with condition as a main between-subjects factor. Results indicated no significant main effects, $p > .10$, all tests, suggesting that the infants' initial and final fixation and their pattern and rate of habituation was comparable across conditions. Thus differences in habituation to the stimulus events could not bias or account for the results of the primary analyses of visual recovery scores.

Recovery scores were again calculated as the difference between mean posthabituation and mean test trial fixation. Visual recovery of the experimental group (M = −1.2 s) was smaller than that of controls (M = +1.4 s). A three-way ANOVA was performed on the recovery scores with test condition (2 levels), habituation rhythm (4) and tempo presentation order (4) as factors, and this resulted in no significant effects ($p > .10$ for tests of main effects and two-way interactions; the three-way interaction was not examined). Follow-up t tests revealed that neither recovery score was significantly different from 0, $p > .10$. Finally, a two-way ANOVA on recovery scores with condition and gender as main factors revealed no significant effects due to infant gender, $p > .10$.

In conclusion, no significant visual recovery was observed for the experimental group infants relative to the controls. In contrast to our hypothesis, there was no evidence that the infants in Experiment 2 abstracted the invariant rhythm across changing tempos, or recognized a novel rhythm-novel tempo on test trials. It did not appear that any of the individual rhythm or tempo-order conditions significantly affected this pattern of results.

GENERAL DISCUSSION

The results of Experiment 1 suggested that 7-month-olds abstracted an invariant stimulus tempo amid changes in rhythm. Our prior study using these stimuli (Pickens & Bahrick, 1995) established that 7-month-olds were capable of discriminating these rhythms and tempos. The term *categorization* has been used to refer to a perceiver treating discriminable events as similar on the basis of a common feature or property. Therefore, the results of Experiment 1 suggest that by 7 months of age, infants showed evidence of categorization on the basis of invariant tempo for events with discriminably different rhythms. This is similar to the way infants have been shown to categorize objects on the basis of physical stimulus attributes such as size, shape, or color (e.g., Cohen & Strauss, 1979; Cohen & Younger, 1983).

In contrast to the results of Experiment 1, 7-month-olds showed no evidence of abstracting an invariant rhythm amid changes in tempo in Experiment 2. Our prior study (Pickens & Bahrick, 1995) demonstrated that the rhythm contrasts presented were discriminable to 7-month-olds (when tempo was held constant). Therefore, an inability to discriminate these rhythms at 7 months did not account for the infants' lack of a response to a novel rhythm in Experiment 2. The absence of a visual recovery in Experiment 2, while it does not conclusively prove that 7-month-old infants could not abstract an invariant rhythm, does suggest that they did not do so in the context of varying event tempos.

From an invariant detection point of view (Gibson, 1969), the results can be taken to suggest that infants directly perceived invariant temporal information. At 7 months of age, the infants were able to abstract an invariant tempo amid changes in rhythm, but were not able to detect an invariant rhythm in the context of changing tempos. Thus detection of invariant tempo may developmentally precede the detection of invariant rhythm. Such developmental sequences in infants' ability to detect various temporal invariants have been proposed previously (Bahrick, 1992, 1994; Bahrick & Pickens, 1994; Lewkowicz, 1994). A more cognitive interpretation might suggest that infants encoded an internal schema, prototype, or representation during habituation to which subsequent events were compared (Cohen & Strauss, 1979; Cohen & Younger, 1983; Mervis & Rosch, 1981). From this perspective, the 7-month-old infants could be described as categorizing stimuli on the basis of tempo, but not rhythm. With development, infants may develop a greater capacity to form more elaborate cognitive prototypes and therefore from this viewpoint might also be predicted to begin to categorize on the basis of rhythm later in development. The results of the current study are thus consistent with both Gibsonian and cognitive categorization models and do not appear to support one view over another.

In the present studies, *all* test conditions presented a change in the temporal structure of the stimuli. Our prior study demonstrated that 7-month-olds responded to a simple change in either the rhythm or the tempo of a bimodal event (Pickens & Bahrick, 1995). However, in Experiment 1 of the present study, in the context of varying rhythm during habituation, infants only responded to a change in two temporal properties of the test stimulus (rhythm plus tempo), but not to a change in rhythm alone. In Experiment 2, in the context of varying tempos during habituation, the infants did not show a recovery of attention to a change in tempo alone, nor to a change in rhythm plus tempo. Thus change in one or even two temporal properties of the test stimulus did not necessarily elicit a response. Apparently, varying the rhythms during habituation did not prevent infants from perceiving an invariant tempo, while varying the stimulus tempo did appear to disrupt their perception of an invariant rhythm.

Perhaps changes in stimulus tempo were more salient to 7-month-olds than the changes in stimulus rhythm, and therefore, shifts in tempo were more disruptive of infants' abstraction of the invariant rhythm. In the current study, infants who received a more extreme tempo contrast showed a greater recovery than infants who received a more intermediate tempo contrast on test trials. In our prior study using these stimulus events (Pickens & Bahrick, 1995), 7-month-olds' mean visual recovery to an intermediate shift in tempo was also smaller than their response to the more extreme change in tempo, and this was a significant difference. Since the infants in that prior study also showed a significant recovery to changes in rhythm, we cannot state that changes in tempo are necessarily "more discriminable" than changes in rhythm. Nevertheless, infants in both the current and prior studies responded more to extreme vs. intermediate tempo shifts. Therefore, because some extreme tempo shifts were presented during habituation in Experiment 2, these may have disrupted the infants' abstraction of an invariant rhythm more than the rhythm shifts in Experiment 1 disrupted their perception of an invariant tempo.

One prior study has reported that 7- to 9-month-olds do show evidence of categorizing on the basis of invariant rhythm across variations in the tempo of 3- and 4-tone acoustic sequences (Trehub & Thorpe, 1989). Their finding is in contrast to the results of Experiment 2 of the current study, which did not observe categorization on the basis of rhythm amid changes in tempo. It is not clear whether this difference in results across studies was due to Trehub and Thorpe's testing of slightly older infants, their use of acoustic stimuli, or their use of a conditioned head turn procedure in contrast to a visual habituation paradigm. Future research should attempt to test infants of different ages, presenting rhythms and tempos with a variety of stimuli, and tapping several testing procedures and infant responses to better determine how these different factors influence the infants' performance. In this way, researchers will begin to distinguish at which points in development, and under which specific conditions, infants are able to abstract invariant temporal structure of events.

To summarize, infants are sensitive to the temporal structure of complex bimodal events. In Experiment 1, 7-month-olds appeared to categorize auditory-visual stimuli on the basis of invariant tempo amid discriminable changes in rhythm. However, when tempo was varied and rhythm was held constant in Experiment 2, the 7-month-olds did not appear to categorize events on the basis of the invariant rhythm. The pattern of results may reflect a developmental sequence in which infants' detection of invariant tempo precedes their detection of invariant rhythm. Another possibility is that differences in the relative salience of rhythm vs. tempo variations presented during habituation may influence the infant's ability to abstract a temporal invariant. Further studies may clarify these issues. However, it is clear that by 7-months old infants not only discriminate event tempos and rhythms, but also appear capable of abstracting an invariant tempo amid concurrent changes in the rhythms of dynamic, bimodal events.

Authors' Note

This research was supported by National Institute of Child Health and Human Development grants (HD-25669) to the second author. Portions of these data were presented at the 1988 International Conference on Infant Studies. Special thanks are extended to Gloria Peruyera, Donna Ott, and Isabelle Diaz for their assistance.

FOOTNOTE

1. Metronome rates used for filming were 70, 110, 160, and 240 beats per min. Taking into account the four-beat measure of rests alternating with each measure of impacts, this translates into 35, 55, 80, and 120 impacts per min, corresponding to 1.2, 1.8, 2.7, and 4 Hz, respectively.

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29 December 1995;
Revised 06 November 1996 ■