Perception of Audiovisual Rhythm and its Invariance in4- to 10-Month-Old Infants

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Abstract:

This study investigated the perception of complex audiovisual rhythmic patterns in 4-, 6-, 8-, and 10-month-old human infants. In Experiment 1, we first habituated infants to an event in which an object could be seen and heard bouncing in a rhythmic fashion. We then tested them to determine if they would detect a relative temporal pattern change produced by rearranging the intrapattern intervals. Regardless of age, infants successfully detected the pattern change. In Experiment 2, we asked whether infants also can extract rhythmic pattern invariance amid tempo variations. Thus, we first habituated infants to a particular rhythmic pattern but this time varying in its tempo of presentation across trials. We then administered one test trial in which a novel rhythm was presented at a familiar tempo and another test trial in which a familiar rhythm was presented at a novel tempo. Infants detected both types of changes indicating that they perceived the invariant rhythm and that they did so despite the fact that they also detected the varying tempo. Overall, the findings demonstrate that infants between 4 and 10 months of age can perceive and discriminate complex audiovisual temporal patterns on the basis of relative temporal differences and that they also can learn the invariant nature of such patterns.

Keywords: infant perception; habituation; rhythmic pattern invariance

Article:

INTRODUCTION

In general, if a series of sounds and/or visible actions is distributed unevenly over a 2–3 s period of time our perceptual system tends to group them together into rhythmic patterns (Fraisse, 1982; Lashley, 1951; Martin, 1972). These kinds of perceptual grouping processes are very useful in infancy because they can help infants segment continuous sensory input into meaningful chunks of information and, thus, enable them to acquire knowledge. Research has shown that infants can group auditory and visual streams of information on the basis of conditional probability relations among the individual elements making up a continuous stream of auditory or visual inputs (Kirkham, Slemmer, & Johnson, 2002; Saffran, Aslin, & Newport, 1996; Saffran, Johnson, Aslin, & Newport, 1999). In addition, research has shown that infants can learn rudimentary grammatical rules governing the temporal distribution of a series of distinct auditory elements (Gómez, 2002; Gómez & Maye, 2005; Marcus, Vijayan, Rao, & Vishton, 1999) and that they can learn the specific order of a series of audiovisual elements and then detect a change in that order (Lewkowicz, 2004).

At a basic level, perceptual grouping depends on a sensitivity to the temporal flow of information. Indeed, evidence indicates that infants are sensitive to various unimodal as well as multimodal attributes of temporal sensory experience (Lewkowicz, 1989, 2000a). In the unimodal realm, it has been found that infants are sensitive to the speed of visual motion (Dannemiller & Freedland, 1991a,b; Kaufmann, Stucki, & Kaufmann-Hayoz, 1985; Roessler & Dannemiller, 1997), to temporal frequency differences in the visual and auditory modalities (Balaban & Dannemiller, 1992; Gardner, Lewkowicz, Rose, & Karmel, 1986; Lewkowicz, 1985a,b, 1988a,b, 1992,1994; Morrongiello, 1984), to differences in the duration of silent intervals separating a series of sounds (Thorpe & Trehub, 1989; Thorpe, Trehub, Morrongiello, & Bull, 1988), and to differences in auditory (Chang & Trehub, 1977a; Demany, McKenzie, & Vurpillot, 1977) and visual rhythmic patterns (Mendelson, 1986). In the multimodal realm, it has been found that infants can perceive auditory-visual relations based on temporal synchrony (Bahrick, 1988; Lewkowicz, 1986, 1992, 1996, 2000b, 2003), duration (Lewkowicz, 1986) and rhythm (Allen, Walker, Symonds, & Marcell, 1977; Mendelson & Ferland, 1982). In addition, it has been found that infants respond in categorically different ways to two visual stimuli moving in an ambiguous fashion with respect to one another depending on whether a sound occurs at the time the visual stimuli overlap or not (Scheier, Lewkowicz, & Shimojo, 2003). Finally, studies have shown that infants can anticipate future events based on the temporal distribution of visual or auditory stimulation (Brooks & Berg, 1979; Canfield & Haith, 1991; Colombo & Richman, 2002; Donohue & Berg, 1991) and that infants can regulate their behavior in temporally appropriate ways when interacting with adults (Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Lester, Hoffman, & Brazelton, 1985; Stern, Beebe, Jaffe, & Bennet, 1977).

One of the most powerful and compelling forms of temporal grouping is rhythm. The perceptual power of rhythm derives from the fact that it imposes an overall temporal structure onto sensory input and, in the process, defines not only adjacent sequential relations but distant ones as well. In other words, unlike statistical relations that are based on pair-wise sequential relations, rhythmic pattern information enables us to perceive the relations among all the elements of a sequence at once. A number of studies have reported that infants can perceive rhythmic pattern information. Unfortunately, interpretation of the evidence from some of these studies is difficult because of problems in stimulus design and/or confounds with other discriminative cues. For example, a study by Demany et al. (1977) has often been cited as evidence of developmentally early rhythm perception in infants. In this study, 2.5- month-old infants, who were habituated to a series of three sounds presented at equal intervals, were able to detect a change in the length of the interval between the first and second sound. Although Demany et al. interpreted this finding as evidence of rhythmic pattern discrimination, a simpler explanation may be that infants responded to the difference in the first intrapattern interval and ignored the overall temporal organization of the two patterns. In another study, Chang and Trehub (1977b) investigated whether 5-month-old infants could discriminate between a 2-4 and a 4-2 temporal grouping of a series of multitone sounds. Results indicated that infants successfully discriminated between the patterns. Unfortunately, because the sounds making up the patterns differed in pitch, it is not clear whether infants based their response on differences in temporal grouping or on pitch-envelope differences.

One way to ensure that true evidence of pattern discrimination is obtained is to incorporate two design requirements. First, the different rhythmic patterns should be composed of identical elements and/or component actions. Second, the set of intrapattern intervals in one rhythmic pattern ought to be identical to those in the contrasting rhythmic patterns and only the relative temporal distribution of the intervals across the contrasting patterns should differ. To illustrate this, consider a series of four identical stimuli. One way to arrange them is to make two groupings of two elements each, creating a 2- 2 rhythmic pattern (see Fig. 1 for a schematic illustration of this). In this case, the intrapattern intervals separating the two stimuli of each grouping are equal and are shorter than the intrapattern interval separating the two groupings from each other. Furthermore, the most effective way to render the two grouping into one unitary 2-2 pattern is to repeat the sequence of the four stimuli while making the interpattern interval separating each iteration of the sequence longer than the longest intrapattern interval. A 3-1 rhythmic pattern can be created from the 2-2 pattern by simply shifting the longer intrapattern interval so that it falls between the third and fourth stimulus elements (see Fig. 1). Critically, the successful perception of a difference between these two patterns depends on the detection of all interval relations and, thus, requires the detection of a relative difference between the contrasting patterns. This, in turn, requires temporal integration across all the intervals in a given pattern and, as a result, is likely to require greater processing resources (Drake & Bertrand, 2003) than the detection of absolute differences in a single intrapattern interval as was the case in the Demany et al. (1977) study.

Morrongiello (1984) was the first to investigate the role of absolute and relative temporal differences on infants' response to rhythmic pattern information. In addition, the rhythmic patterns in this study were longer (4.2 s) and more complex than in previous studies and were composed of identical sounds (i.e., white noise bursts). Morrongiello found that 6- and 12-month-old infants made successful discriminations on the basis of absolute differences (i.e., the absolute durations of the intrapattern intervals) but that only 12-month-old infants made successful discriminations on the basis of relative differences. In a subsequent study, Mendelson (1986) also reported discrimination of relative rhythm contrasts of visual patterns in 4-month-old infants, although the patterns in this study were shorter in overall duration and simpler than those presented by Morrongiello (1984).

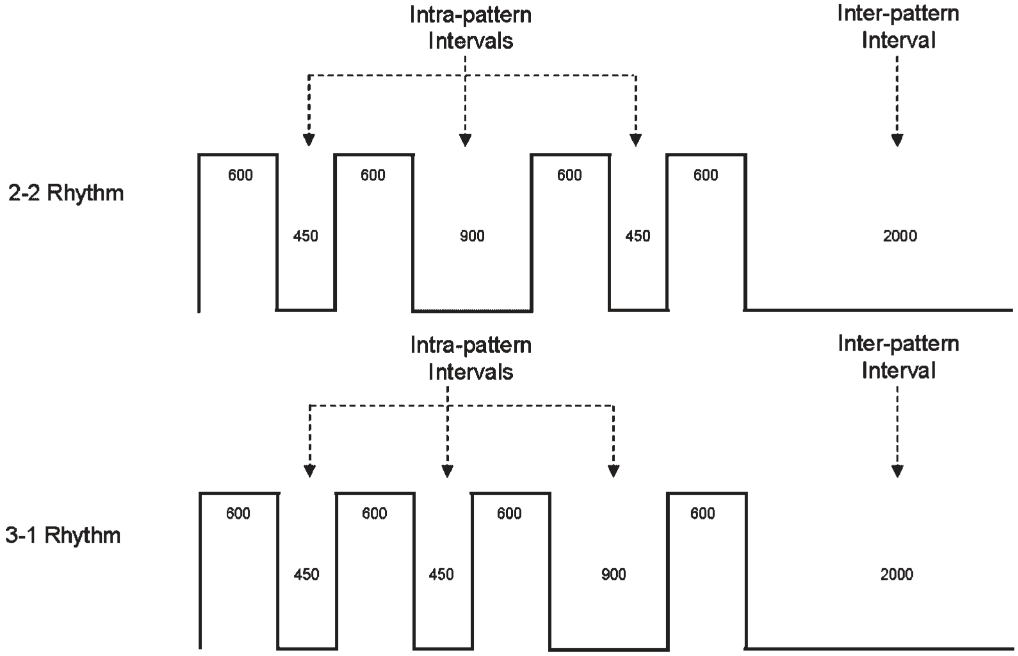

FIGURE 1 Schematic diagram of two different rhythmic patterns and their intra- and interpattern intervals. Each bar represents a single cycle of a discrete and identical action and the numbers inside the bar indicate the duration of the action and the numbers in-between the bars indicate the duration of the rest periods (i.e., the intrapattern intervals).

The Morrongiello (1984) findings reveal that when the task requires that infants discriminate between fairly long and complex rhythmic patterns, they can only respond to absolute differences whereas older infants can respond to relative differences. Other evidence is generally consistent with the developmental trend toward the later emergence of responsiveness to relational information. For example, in the music domain, Trainor and Trehub (1992) have found that 8-month-old infants can recognize transpositions of a melody across different pitches. Similarly, in the speech domain, Houston and Jusczyk (2003) have found that 7.5-month-old infants attend primarily to specific talker identity when learning words but that 10-month-old infants can generalize across talkers' gender and, thus, can perceive more abstract phonetic information across talkers. Interestingly, when processing demands are increased (by inserting a retention interval between familiarization and test), infants appear to resort back to responsiveness to specific surface characteristics and no longer respond to the relational attributes. For example, when 6-month-old infants are familiarized with melodies and then tested a week later, they retain the specific tempo and timbre (i.e., instrument) characteristics of those melodies (Trainor, Wu, & Tsang, 2004). These findings suggest that the ability to perceive relational stimulus features emerges later in development and that the specific timing of the developmental emergence of such abilities depends, in part, on the difficulty of the information-processing task.

This later emergence of responsiveness to relational stimulus features raises an interesting question with regard to the processing of relational rhythmic pattern differences. Might the emergence of the ability to perceive relative rhythm contrasts, particularly when the rhythmic pattern information is complex, occur earlier in development if the information is redundantly specified in multiple sensory modalities? Evidence from studies of the adults of many different species shows that reaction times to multimodal signals are faster and more accurate and that stimulus recognition of multimodal signals is better than of unimodal signals (Partan & Marler, 1999; Rowe, 1999). Evidence from infant studies also demonstrates that redundancy facilitates learning and discrimi-nation (Bahrick & Lickliter, 2000; Lewkowicz, 2000a, 2004; Lewkowicz & Kraebel, 2004). Although the ability to perceive intermodal relations is not essential to obtaining redundancy effects, it is certainly helpful and, in fact, studies show that infants can perceive various types of intermodal relations

(Lewkowicz, 2000a; Lewkowicz & Lickliter, 1994; Lickliter & Bahrick, 2000; Walker-Andrews, 1997). Finally, studies specifically concerned with rhythm perception suggest that infants can perceive redundantly specified relative rhythm contrasts earlier than unimodally specified contrasts. For example, whereas only 12-month-old infants successfully perceive relative auditory rhythm contrasts (Morrongiello, 1984), younger infants can perceive such contrasts if the rhythmic patterns are multimodally specified (Bahrick & Lickliter, 2000; Lewkowicz, 2003; Pickens & Bahrick, 1997).

One question that has not been addressed to date is whether multimodal redundancy might facilitate rhythm perception in the face of increased processing load. In general, the longer and more complex a rhythmic pattern is, the more likely it is that integration of the temporal information inherent in that pattern becomes more difficult (Drake & Bertrand, 2003). Presumably, this is due to short-term memory limitations. It is possible that multimodal redundancy might be able to counteract the greater processing load of a longer temporal pattern. If that is the case then infants younger than 12 months of age may be able to learn and discriminate multimodal relative rhythm contrasts inherent in longer and more complex rhythmic patterns than have been presented to date. This prediction receives indirect support from the fact that infants as young as 4 months of age can perceive relative audiovisual rhythm contrasts (Lewkowicz, 2003), which is 8 months earlier than the ability to perceive such contrasts in auditory patterns (Morrongiello, 1984). The problem with this comparison, however, is that the rhythmic patterns presented in the Lewkowicz (2003) study were shorter than those presented by Morrongiello (1984). Additionally, Mendelson's (1986) finding that 4- month-old infants can perceive relative rhythm contrasts of visual-only rhythmic patterns runs counter to the prediction. Thus, the only way to answer the question is to test young infants with audiovisual rhythmic patterns that are longer and more complex than the longest rhythmic patterns presented to date. If infants younger than 12 months of age can perceive the more complex relative rhythm contrasts then it would be reasonable to conclude that multimodal redundancy can, indeed, facilitate rhythm perception in the face of increased processing load.

The current study consisted of two experiments. To make sure that we covered a broad developmental range and, thus, captured any possible developmental differences, we sampled perception of relative rhythm contrasts in 4-, 6-, 8-, and 10-month-old infants. In Experiment 1, we investigated learning and discrimination of audiovisual rhythmic patterns that were considerably longer and more complex than any rhythmic patterns presented to date. In Experiment 2, we investigated whether infants can detect rhythmic pattern invariance amidst tempo variations.

EXPERIMENT 1

To investigate rhythm perception, we habituated infants to an audiovisual event consisting of an object resembling a basketball bouncing up and down rhythmically while it made impact sounds each time it reversed direction at the bottom of its motion trajectory. Following habituation, we tested discrimination by presenting the same event but arranged in a different rhythmic pattern. Importantly, the contrasting patterns only differed in terms of the relative temporal arrangement of intrapattern intervals and, thus, required infants to integrate all the intrapattern intervals to successfully detect the difference between the patterns.

Method

Participants. We tested a total of 96 infants, with groups of 24 infants each at one of four ages. The 4-month-old group of infants consisted of 10 boys and 14 girls (age: M = 19.2 weeks, SD =.8 weeks), the 6-month-old group consisted of 14 boys and 10 girls (age: M = 27.8 weeks, SD =.9 weeks), the 8-month-old group consisted of 9 boys and 15 girls (age: M = 36.3 weeks, SD =.8 weeks), and the 10 month-old group consisted of 12 boys and 12 girls (age: M = 45.1 weeks, SD = 1.2 weeks). We tested one additional 8-month-old and three additional 10-month-old infants but did not include them in the final sample because they were fussy.

Apparatus and Stimuli. Infants were seated either in an infant seat or on a parent's lap in front of a 17 in computer monitor at an approximate distance of 50 cm from the monitor. A camcorder was located on top of the stimulus-display monitor. The experimenter, who was located in a separate control room, was able to view the infant's face on a monitor located in the control room. The experimenter wore a set of headphones throughout the experimental session and listened to continuous broad-band noise. As a result, the experimenter could neither see nor hear the stimuli being presented to the infant.

The stimulus materials consisted of four different audiovisual events that were presented as multimedia movies. The movies were played by a personal computer (PC) and displayed on the stimulus-display monitor. The PC also kept track of infant looking times during the experiment by monitoring the experimenter's mouse presses. One movie (the attention-getter) showed a continuously expanding and shrinking green disk that subtended 6.86 degrees of visual angle at its smallest size and 18.74 degrees at its largest size. The attention-getter movie was used to attract the infant's attention toward the stimulus-display monitor. The second movie consisted of a segment of a Winnie-the-Pooh cartoon and its main purpose was to measure the infant's initial and terminal levels of attention during the experiment and, thus, rule out possible fatigue effects. We used the remaining two movies to investigate perception of rhythm. These movies depicted a colored object resembling a basketball (subtending 2.52 degrees of visual angle) bouncing up and down in a rhythmic fashion while making an impact sound each time it reached the bottom of its motion trajectory. The impact sound was a digitized recording of a hammer striking against a surface at an intensity of 80 dB SPL (the ambient room SPL was 50 dB). All movies were produced with the aid of Adobe Corporation's After Effects program. The movies of the two rhythmic patterns were made by importing the basketball image and the impact sound into after effects and then animating the visual image to resemble a bouncing/sounding basketball.

Each movie began with the appearance of the basket-ball in the middle of a black background on the computer monitor. As soon as the basketball appeared, it began to move down at a constant speed for 300 ms and over a distance of 8 cm. When the basketball reached the bottom of its motion trajectory it reversed direction and, as it did so, the impact sound was presented. The basketball then moved back up at the same constant speed for another 300 ms until it reached its original starting point. This single bounce cycle served as the building block for making the rhythm movies. In one of these movies the basketball could be seen and heard bouncing in a 2-1-3 rhythmic pattern. In the other movie, the basketball could be seen and heard bouncing in a 2-3-1 rhythmic pattern. Figure 2 shows in schematic form the two rhythmic patterns and their specific temporal parameters (the overall tempo at which this pattern was presented was .68 Hz). Once a single pattern consisting of the six visible/ audible bounces was completed, the basketball rested at the top of its trajectory for 2000 ms. At the end of this rest period, the pattern was repeated and continued to be repeated as long as the infant kept looking at the movie (see below).

Procedure and Design. We used the infant-controlled habituation/test procedure. This meant that each time the infant looked at the stimulus-presentation monitor, the experimenter initiated movie presentation by depressing a button on a computer mouse connected to the computer. The movie played as long as the infant continued to look at the monitor and ended either when the infant looked away from the monitor for more than 1 s or when 48 s elapsed (the latter was designated as the maximum allowable trial length). When either condition was met, the attention-getter appeared on the screen and only disappeared when the infant looked back at the monitor. As soon as the infant looked back, the next trial commenced.

The experiment began with a single pretest trial during which the cartoon movie was presented. Its purpose was to provide a measure of the infant's initial level of attention. The next trial constituted the start of the habituation phase. The infants at each age were divided into two habituation groups. One group was habituated to a 2-1-3 rhythmic pattern whereas the other was habituated to the 2-3-1 rhythmic pattern. The total number of habituation trials administered to a given infant depended on a predetermined habituation criterion that required the infant to reduce his/her total duration of looking during the last three trials of the habituation phase to 50% of the total duration of looking during the first three trials. As soon as the infant reached the habituation criterion, the test phase began and consisted of two test trials presented in counterbalanced order. One was a familiar rhythm (FR) test trial during which the same rhythmic pattern that was presented during the habituation phase was presented again. The other was a novel rhythm (NR) test trial during which the novel rhythmic pattern was presented. Finally, to measure the terminal level of attention, infants were given a posttest trial during which the Winnie-the-Pooh cartoon was played again.

Results and Discussion

The distribution of looking duration during the FR test trial was examined first to determine whether any infants exhibited spontaneous regression to the mean (Bertenthal, Haith, & Campos, 1983). The test trial data from infants who exhibited looking durations in the FR test trial that fell into the outlier and beyond range (i.e., more than 1.5 interquartile range units above the third quartile) were excluded. Based on this criterion, the data from one 4-month-old, one 6-month-old, and one 8-month-old infant were excluded from analyses.

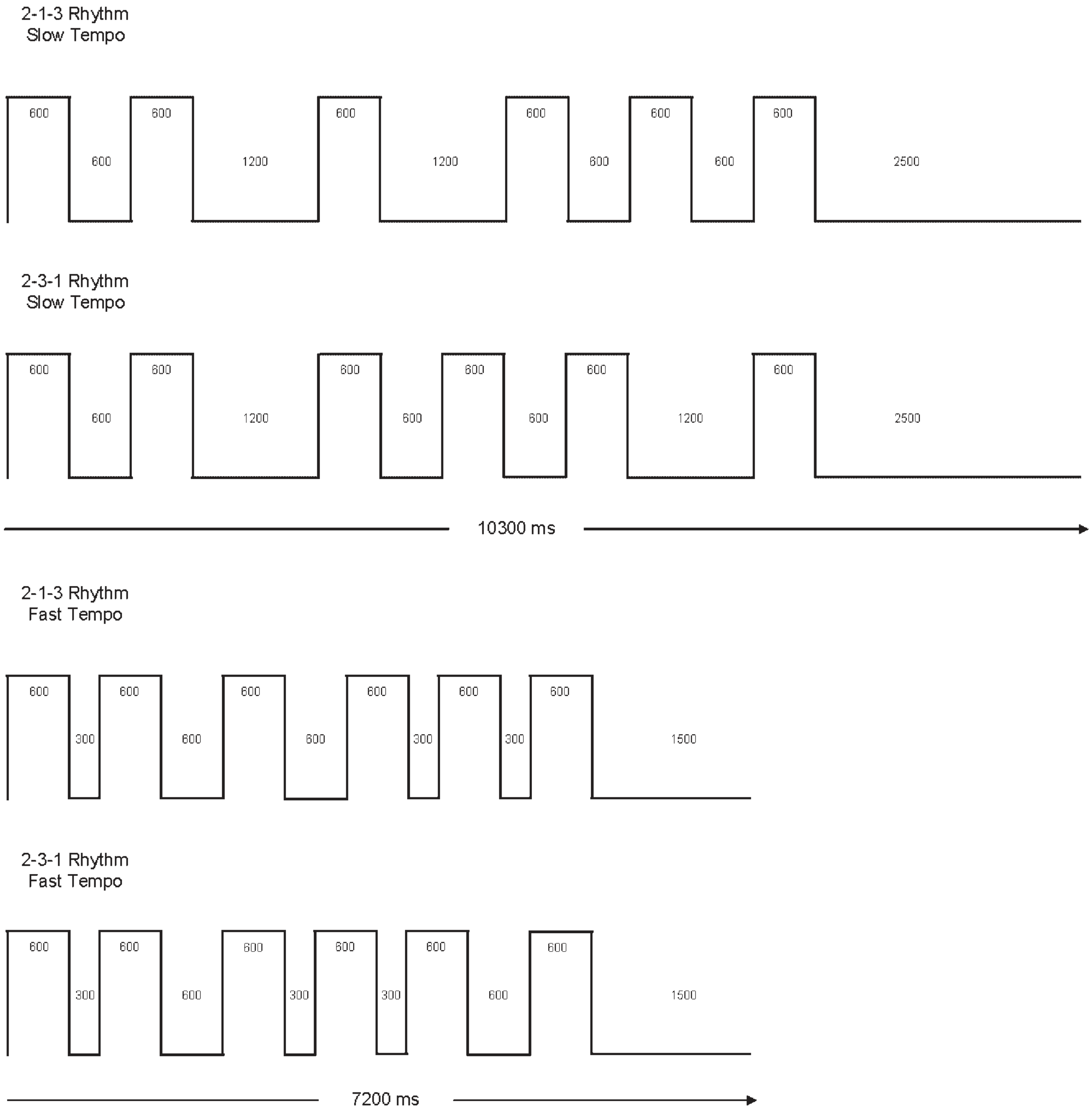

FIGURE 2 Schematic diagram of the two rhythmic patterns and their temporal parameters (in milliseconds) presented in Experiment 1. Each bar represents a single cycle of down and up motion of the basketball. The impact sound occurred 300 ms into each cycle of motion. The numbers inside the bar indicate the duration of the action and the numbers in-between the bars indicate the duration of the rest periods (i.e., intrapattern intervals).

The test trial data from the remaining 93 infants were analyzed by way of a 4 x 2 x 2 x 3 (age x habituation group x trial order x trial type) repeated-measures analysis of variance (ANOVA), with age, habituation group and trial order as the between-subjects factors and trial type as the within-subjects factor. The ANOVA indicated that there was a main effect of age, F(3, 77) = 3.95, $p < .05$, but no significant age x trial type interaction. In addition, there was a main effect of trial type, F(1, 77) = 13.62, $p < .00 1$, indicating that infants exhibited response recovery to the novel rhythmic pattern (see Fig. 3).

The findings from this experiment indicated that, regardless of age, infants between 4 and 10 months of age discriminated between two temporally complex audio-visual rhythmic patterns. Of particular importance is the fact that infants could not have succeeded in discriminating between the two patterns on the basis of the first one or two intrapattern intervals nor on the basis of element identity. Rather, they could only have succeeded by perceiving the relative ordering of the short (450 ms) and long (900 ms) intrapattern intervals.

EXPERIMENT 2

Typically, in the real world, temporal dimensions covary. For example, a particular rhythmically organized pattern can occur at different tempos. Because of our propensity for attending to relational information, however, we tend to ignore the tempo variations and perceive the invariant pattern information (Fraisse, 1982). The ability to perceive rhythmic pattern invariance reflects the general process of categorization that enables us to organize continuously varying information into cognitively manageable chunks. This fact raises the question of when in development infants are able to perceive invariant temporal patterns. The answer to this question is not clear because only two studies have investigated it and the results from one study are open to other interpretations whereas the results from another study provide negative evidence in this regard. Thus, Trehub and Thorpe (1989) tested 7- to 9-month-old infants' response to auditory rhythmic pattern invariance and found that infants categorized the patterns on the basis of temporal grouping. Unfortunately, the first grouping of sounds in this study differed across contrasting patterns (1-2 vs. 2-1, and 2-2 vs. 3-1) raising the possibility that infants did not base their response on pattern information per se. Pickens and Bahrick (1997) tested 7-month-old infants' response to invariant audiovisual rhythms presented at one of three different tempos. Findings indicated that infants did not learn the invariant rhythms.

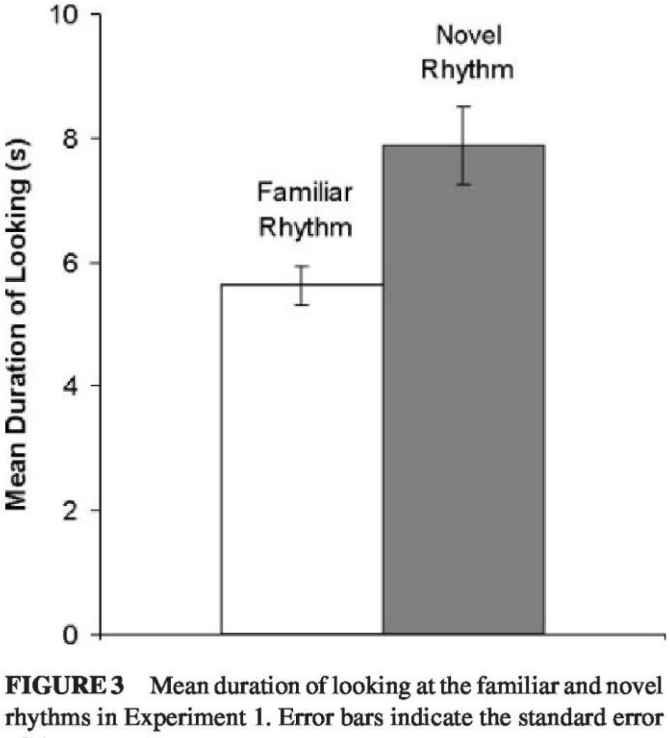

FIGURE 3 Mean duration of looking at the familiar and novel rhythms in Experiment 1. Error bars indicate the standard error of the mean.

Because the question of whether infants can perceive invariant rhythmic patterns is still an open one, the purpose of Experiment 2 was to investigate this issue. To do so, in this experiment we habituated infants to one of the audiovisual rhythmic patterns presented in Experiment 1 except that here we presented this pattern at two different tempos across different habituation trials. We chose to present the pattern at two, rather than three different tempos as was the case in the Pickens and Bahrick (1997) study, partly in an effort to reduce the information-processing load. Following habituation, we administered two test trials. In one test trial, we presented a novel rhythmic pattern at one of the familiar tempos to determine whether infants learned the invariant rhythmic pattern. If they did then they were expected to exhibit response recovery to the novel rhythm. In the other test trial, we presented a familiar rhythmic pattern but at a novel tempo to determine whether infants learned to ignore the tempo variations. If they did then they were expected to exhibit no response recovery. If, however, they detected the tempo change as well as the rhythm change then this would suggest that they learned the invariant pattern without ignoring the tempo variations.

Method

Participants. We tested a total of 96 infants, with groups of 24 infants each, at 4, 6, 8, and 10 months of age. The 4-month-old group consisted of 14 boys and 10 girls (age: M = 18.8 weeks, SD = 1.0 weeks), the 6-month-old group consisted of 11 boys and 13 girls (age: M= 27.8 weeks, SD=.9 weeks), the 8-month-old group consisted of 11 boys and 13 girls (age: M = 36.2 weeks, SD = .9 weeks), and the 10-month-old group consisted of 14 boys and 10 girls (age: M=45.0 weeks, SD= 1.2 weeks). We tested an additional eight infants but did not include them in the final sample because they were fussy (two 4-month-olds, one 6-month-old, three 8- month-olds, and two 10-month-olds).

Apparatus and Stimuli. The apparatus and stimulus materials were identical to those used in Experiment 1 except that two additional movies were constructed. In these movies, the basketball once again bounced and sounded in a 2-1-3 or a 2-3-1 rhythmic pattern, but this time it did so either at a slower tempo (.58 Hz) or at a faster tempo (.83 Hz) than in the movies presented in Experiment 1. Figure 4 shows the temporal parameters of the slower and faster patterns.

Procedure and Design. The procedure was identical to the procedure used in Experiment 1 except that the design depicted in Table 1 was used. As can be seen, half the infants were habituated to the 2-1-3 rhythmic pattern and the other half were habituated to the 2-3-1 rhythmic pattern. For each infant, the habituation phase consisted of alternating trials during which the rhythmic pattern was presented either at the fast or at the medium tempo. For the test trials, each group was subdivided into two groups that differed in terms of the specific tempo at which the rhythms in the FR and the NR test trials were presented. Thus, as can be seen in Table 1, the rhythm in the FR and the NR test trial was presented at a fast tempo for one subgroup of each rhythm-pattern group and at a medium tempo for the other subgroup. The tempo of the familiar rhythmic pattern presented in the novel tempo (NT) test trial was slower than the tempos presented during the habituation phase. The slower tempo ensured that successful discrimination was not based on an increase in the overall amount of stimulation but rather on tempo per se. The order of all three test trials was counterbalanced such that each type of test trial was presented equally often in each ordinal position across infants at each age. The posttest trial was administered following the last test trial.

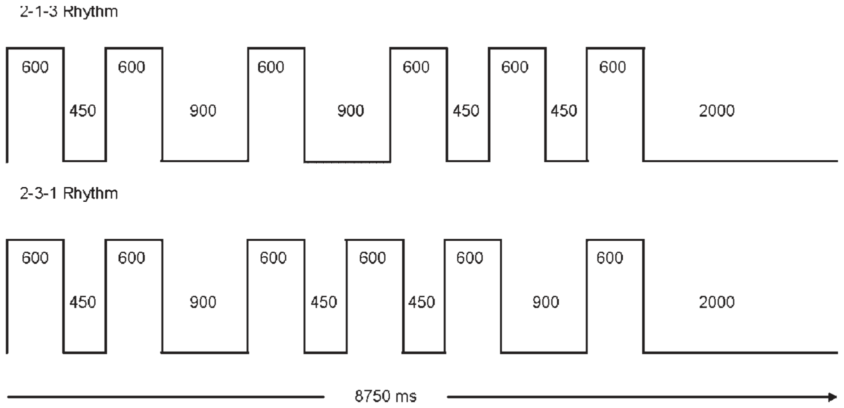

FIGURE 4 Schematic representation of the slow and fast rhythmic patterns presented in Experiment 2 and their temporal parameters.

To provide infants with a sufficient opportunity to become familiar with the rhythmic pattern during the habituation phase, the habituation criterion in this experiment was increased to four trials. This meant that in order for the habituation phase to end, the total duration of looking during the last four habituation trials had to decrease to 50% of the total duration of looking during the first four trials. In addition, maximum trial length was increased to 60 s to permit infants more time to encode the patterns.

Results and Discussion

Given that habituation trial length was increased to 60 s, we first examined the habituation data to determine whether looking during the habituation trials in this experiment differed from looking during Experiment 1. Despite the longer trial length in this experiment, infants looked for virtually identical amounts of time across the first six habituation trials in both experiments. A 2 x 6 (experiment x habituation trials) repeated measures ANOVA, with experiment as the between-subjects factor and habituation trials as the within-subjects factor, revealed a significant overall habituation trials effect, F(5, 870)=159.45, p<.001 but no experiment x habituation trials interaction. These results indicate that infants looked for similar amounts of time during the habituation phase in Experiments 1 and 2.

Examination of responsiveness during the test trials once again consisted of an initial determination of whether any infants exhibited looking durations in the FR test trial that fell into the outlier or extreme range. This resulted in the elimination of the data from three 4-month-olds, three 8-month-olds, and one 10-month-old infant. The test trial data from the remaining 89 infants were analyzed by way of a 4 x 4 x 3 x 3 (age x habituation group x trial order x trial type) repeated-measures ANOVA with age, habituation group and trial order as the between-subjects factors and trial type as the within-subjects factor. The ANOVA yielded a main effect of test trial type, F(2, 82) = 4.84, p < .05, and a trial type x trial order interaction, F(4, 82) = 2.8 1, p < .05.

Table 1. Experimental Design of Experiment 2

	Test Trials		
Habituation Group	Familiar Rhythm (FR)	Novel Rhythm (NR)/ Familiar Tempo	Novel Tempo (NT)/ Familiar Rhythm
2-1-3 fast tempo 2-1-3 medium tempo	2-1-3 fast tempo	2-3-1 fast tempo	2-1-3 slow tempo
2-1-3 fast tempo 2-1-3 medium tempo	2-1-3 medium tempo	2-3-1 medium tempo	2-1-3 slow tempo
2-3-1 fast tempo 2-3-1 medium tempo	2-3-1 fast tempo	2-1-3 fast tempo	2-3-1 slow tempo
2-3-1 fast tempo 2-3-1 medium tempo	2-3-1 medium tempo	2-1-3 medium tempo	2-3-1 slow tempo

The interaction was due to a higher response in the NR test trial relative to the response in the FR test trial in those infants who received the FR test trial first followed by the NR test trial than in those infants who received those two test trials in the other two orders. Despite this effect, however, the pattern of responsiveness was similar across all three test trial orders. Figure 5 shows the data from the test trials collapsed over test trial order. As can be seen in Figure 5, infants looked longer in both novel test trials. To determine whether this increased responsiveness was statistically significant, the overall ANOVA was followed up with planned comparison tests contrasting the duration of looking in the NR and NT test trials, respectively, versus the duration of looking in the FR test trial. These analyses yielded a significant response recovery in the NR test trial, F(1, 4 1) = 7.53, p < .0 1, and a significant response recovery in the NT test trial, F(1, 41) = 6.45, p < .05.

The findings from this experiment showed that infants learned the invariant rhythmic pattern despite variations in its tempo during the habituation phase and that they perceived a change in that rhythm during the test trials. Thus, these findings indicate that, regardless of their age, infants extracted the invariant rhythmic pattern. Interestingly, however, the results also indicated that infants perceived the tempo differences. This suggests that when infants learned to extract invariant rhythm during the habituation phase, they did so by actively disregarding the perceptible tempo variations.

GENERAL DISCUSSION

The current study investigated the perception, learning, and discrimination of complex, audiovisual rhythmic patterns across a broad age range in infancy. The rhythmic patterns presented in the current study consisted of a set of six identical visible actions accompanied by identical audible impact sounds. In addition, the set of intrapattern intervals was identical across the pattern; the only difference between them was the relative temporal order of the intervals in the patterns. As a result, infants could not have discriminated between the patterns on the basis of a single intrapattern interval or the specific identity of a particular pattern element; they could only have succeeded in the task if they perceived the global temporal structure of the patterns. The results of Experiment 1 demonstrated that, regardless of their age, 4- to 10-month-old infants successfully learned and discriminated complex audiovisual rhythms on the basis of relative temporal differences. Experiment 2 showed that, regardless of age, 4- to 10-month-old infants also successfully learned an invariant rhythmic pattern amidst variations in its tempo and that they did so despite the fact that they were aware of the tempo variations.

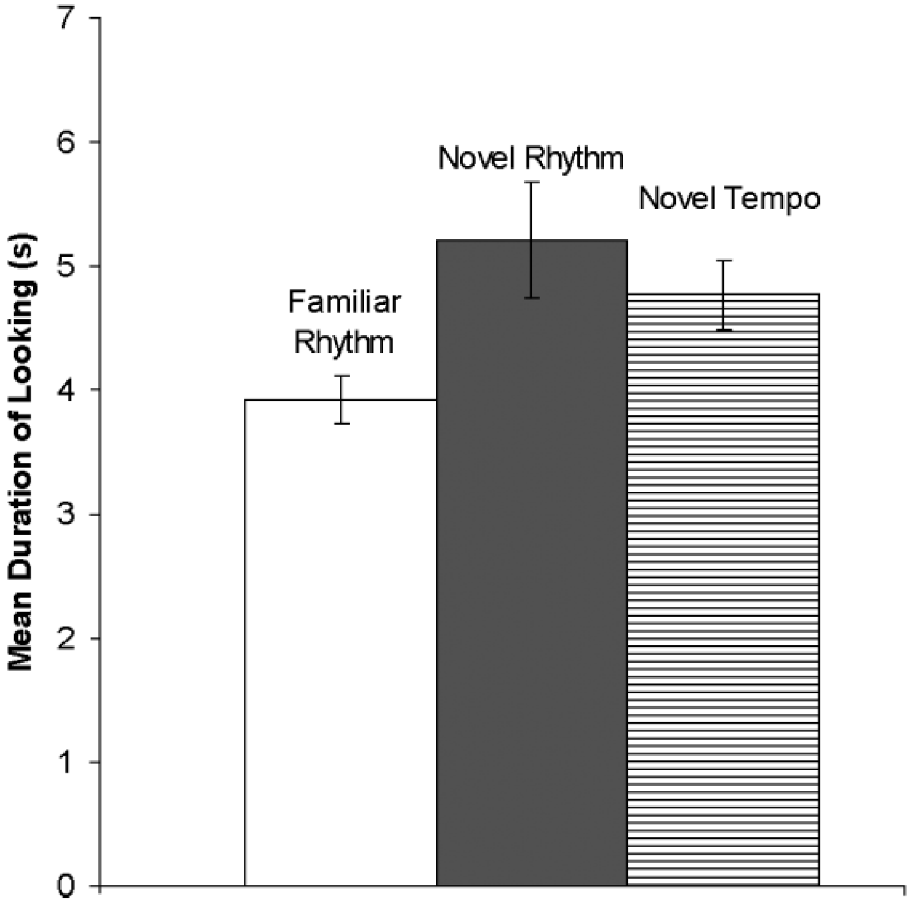

FIGURE 5 Mean duration of looking at the novel rhythm and novel tempo relative to looking at the familiar rhythm in Experiment 2. Error bars indicate the standard error of the mean.

Prior studies have found that infants can learn audiovisual rhythmic patterns and that they can discriminate between them on the basis of relative pattern differences. For example, one of these studies has shown that infants as young as 4 months of age can discriminate between audiovisual rhythms on the basis of relative differences (Lewkowicz, 2003). Two other studies have shown that somewhat older infants (5- and 7-month-olds) can do so as well (Bahrick & Lickliter, 2000; Pickens & Bahrick, 1995, 1997). Importantly, however, the rhythmic patterns presented in these three studies were considerably shorter and temporally simpler than the rhythmic patterns presented in the current study. For example, the rhythmic patterns presented by Lewkowicz (2003) consisted of four component bimodal elements and had an overall duration of 2.3 s. Similarly, the rhythmic patterns presented by Bahrick and Pickens (1995, 1997) and Bahrick and Lickliter (2000) consisted of four component bimodal elements and had an overall duration of 2.18 s. In contrast, the rhythmic patterns presented in the current study were longer and temporally more complex in that they had an overall duration of 6.75 s and consisted of six component elements. Despite the more complex nature of the rhythmic patterns presented in the current study, infants successfully perceived them and extracted their invariant attributes. Thus, the present results extend the findings from earlier studies and show that infants as young as 4 months of age can perceive relatively long and complex audiovisual rhythmic pat-terns. Importantly, the design of the rhythmic patterns presented in the current study rules out the possibility that infants responded to some local feature of the patterns and, instead, leads to the conclusion that successful responsiveness was based on infants' response to the global relational aspects of the patterns.

It is interesting to compare our findings with earlier findings from studies of infants' response to relative rhythmic pattern contrasts. In our study we found that infants as young as 4 months of age can detect relative rhythm contrasts of complex audiovisual rhythmic patterns. In contrast, Morrongiello (1984) found that it is not until 12 months of age that infants respond to relative rhythm contrasts of auditory-only patterns (Morrongiello, 1984). One possible reason for this age difference may be the multimodal versus unimodal character of the stimuli. Multimodal facilitation of responsiveness has been documented in adults (Rowe, 1999) as well as in infants (Bahrick, Lickliter, & Flom, 2004; Lewkowicz & Kraebel, 2004) and, thus, it is possible that our finding of an earlier response to relative rhythmic pattern contrasts is due to the multimodal nature of our stimuli.

The findings from Experiment 2 that, regardless of age, 4- to 10-month old infants perceived rhythmic pattern invariance differ from Pickens and Bahrick's (1997) failure to obtain evidence of rhythmic pattern invariance detection. Differences in the nature of the rhythmic patterns and the way that they were presented across the two studies most likely accounts for the different outcomes in the two studies. Specifically, the rhythmic patterns presented by Pickens and Bahrick (1997) were shorter than those presented here. It is likely that a shorter rhythmic pattern would make it easier, not harder, for infants to detect rhythmic pattern invariance. Thus, pattern length is not likely to be the source of the different outcomes in the two studies. The more likely source may be the fact that the infants in the Pickens and Bahrick study (1997) were habituated with a rhythmic pattern presented at three different tempos whereas the infants in the current study were habituated with a rhythmic pattern presented at two different tempos. Presumably, having to encode fewer tokens of an invariant rhythmic pattern makes it easier for infants to extract rhythmic pattern invariance and, thus, is a reflection of processing-capacity limitations.

The finding that infants can perceive the temporal structure of complex audiovisual rhythmic events and that they can perceive their constancy demonstrates that, from an early age, infants possess the perceptual mechanisms to embark on a process of discovering the temporal structure of their perceptual world. This basic mechanism is critical to the acquisition of higher-level perceptual and cognitive knowledge about a world that has both a determinate and a variable temporal structure. The trick is to discover the determinate temporal structure, to ignore the variations in irrelevant dimensions, and in the process construct categories of information. Pickens and Bahrick (1997) showed that 7-month-old infants are able to detect invariant tempo variations amid rhythmic pattern variations and our results showed that 4- to 10-month-old infants can detect invariant rhythm variations amid tempo variations. Recently, Hannon and Johnson (2005) have added to this evidence by showing that 7-month-old infants are able to categorize auditory rhythmic patterns on the basis of an inferred underlying metrical structure. Together, these findings suggest that the perceptual foundations needed for the construction of stable and invariant categories of temporal perceptual experience are operational in infancy.

In conclusion, the current findings add to the growing body of evidence that infants possess a broad array of temporal learning and discrimination abilities. Temporal information can range from simple durations to complex structures created by concatenating different durations into different rhythmically organized patterns and sequences. The latter are particularly useful from a functional standpoint because they provide a ready-made basis for organizing continuous sensory input into meaningful chunks of information. An especially compelling illustration of the importance of rhythm as an organizing perceptual device is the way that rhythm helps to segment fluent speech right at birth. Nazzi, Bertoncini, and Mehler (1998) have shown that newborn infants use rhythmic information to segment fluent speech and that they use this information to classify utterances into broad language classes. Based on this finding, Nazzi and Ramus (2003) have proposed that sensitivity to the rhythmic properties of speech at the utterance/suprasegmental level enables newborns to begin the process of learning the common rhythmic properties of their native rhythmic class and that this early sensitivity makes it possible for infants to discover the metrical segmentation rules for their native language during the ensuing months of life (Nazzi, Jusczyk, & Johnson, 2000). From the current perspective, the most interesting aspect of Nazzi and Ramus' proposal is that sensitivity to rhythm, rather than recognition of the infant's native language, initially supports language discrimination. In other words, rhythm appears to play a fundamental role in language acquisition and is likely to play a similar role in the development of other psychological domains such as event perception and interpersonal interaction. Rhythm's unique contribution to development is its power to organize a temporal world characterized by otherwise continuous physical sensory input into perceptually and cognitively meaningful chunks of information that can ultimately serve as a basis for the construction of cognitively meaningful categories of experience.

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