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Influences of Temporal Fluctuation on Infant Attention

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We examined infants' attention to sound sequences as a function of the regularity of timing and the relative familiarity of the sequences (first five trials and last five trials). Infants' attention to the regular and irregular sequences was assessed by a means of a preferential looking (listening) procedure. Infants 6–8 months of age listened longer to the regular sound sequences, but only during the last five trials. Infants 9–11 months of age did not show evidence of differential listening on the basis of sequence regularity, but their attention waned from earlier to later trials.

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SALIENT beginnings, recognizable rhythms, characteristic tempos, and lawful endings are important temporal features of our auditory environment (Large & Jones, 1999). Auditory events can be understood in terms of predictability (Jones, 1990): A soothing lullaby exemplifies a highly predictable event, and a sudden exclamatory vocalization exemplifies a relatively predictable event.

Infants can detect subtle auditory events, including 2-ms gaps between brief tones (Trehub, Schneider, & Henderson, 1995) and small duration differences (Morrongiello & Trehub, 1987). They also detect global or structural changes in the organization of sound sequences. At 2 and 4 months of age, they detect a 15% acceleration from a base isochronous sound sequence of intermediate tempo (600-ms interonset interval, or IOI), but not when the base sound sequence is faster (100- or 300-ms IOI) or slower (1500-ms IOI), revealing performance within adults' optimal range (300–800 ms) of tempo discrimination (Baruch & Drake, 1997). Both infants and adults group sequences of sounds by the temporal prox-

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imity of elements (Demany, McKenzie, & Vurpillot, 1977; Fraisse, 1982; Trehub & Thorpe, 1989). Thus, there are at least some similarities in the temporal processing skills of infants and adults.

Hannon and Trehub (in press) suggest that the perception of metric structure may not be crystallized by 6 months of age. They found that North American adults could differentiate meter-preserving from meter-violating variations of simple-meter patterns, which are typical in Western music, but they did not differentiate such variations of complex-meter patterns, which are found in the music of the Eastern Europe, the Middle East, Africa, and South Asia. By contrast, adults of Bulgarian or Macedonian origin, who are familiar with simple- and complex-meter patterns, differentiated meter-preserving from meter-violating variations in the context of simple and complex meters. Interestingly, 6-month-old North American infants who had had limited exposure to Western music differentiated the meter-preserving and meter-violating variations in both meter patterns.

The aforementioned studies indicate that infants are capable of discriminating sound sequences, but they are doing so on the basis of culture-specific exposure. Adult-infant differences in temporal processing may arise from experiential biases on the part of adults rather than adult-infant resolution differences.

There has been considerable research on infants' responsiveness to the maternal speech style. When given a choice of listening to infant- or adult-directed speech, infants show attentional and affective preferences for infant-directed speech (for a review, see Fernald, 1991). The prevailing view is that infants' preference arises largely from the exaggerated pitch contours of infant-directed speech. Fernald and Kuhl (1987) exposed infants to a variety of simulations of infant- and adult-directed speech, which were based on the pitch modulation, the amplitude modulation, or timing modulation of infant- and adult-directed speech samples. Four-month-old infants listened preferentially to infant-directed over adult-directed versions only for samples that simulated the pitch modulation of those types of speech. Although Fernald and Kuhl's (1987) findings have been cited widely, design problems preclude a clear interpretation. Because the original timing of utterances remained intact in the pitch-modulation condition, infants had timing as well as pitch contour cues in that condition, in contrast to timing *or* intensity cues only in the other conditions. It is possible, then, that pitch contour alone would not maintain infants' attention, as Fernald and Kuhl (1987) proposed. Colombo and Horowitz (1986) tested infants' preferences with habituation as well as preference procedures. They found no preference for infant-directed over adult-directed speech when infants received pitch modulation cues alone. It is possible that the timing or rhythm of infant-directed utterances plays an important role in attracting and maintaining infants' attention, but this possibility has not been investigated to date.

In addition to speaking in a playful or soothing manner, mothers sing to their infants to maintain their attention or reduce their distress. The impact of such music must underlie its increasing use in neonatal intensive care units (Cassidy & Standley, 1995). There is evidence that such singing modulates the arousal level of healthy, nondistressed infants, as reflected in salivary cortisol levels (Shenfield, Trehub, & Nakata, 2003). In fact, the arousal consequences of maternal singing are more enduring than those of maternal speech (Shenfield, Trehub, & Nakata, 2002).

Nakata and Trehub (2004) presented 6-month-old infants with video recordings of their own mothers' speaking or singing. Infants remained attentive for significantly longer during the singing episodes than during the speech episodes. The temporal coherence or regularity in tempo of singing plays an important role in maintaining infants' engagement. According to Bergeson and Trehub (2002), infant-directed singing is much more uniform in tempo, rhythm, and dynamic range than is infant-directed speech.

Drake and Bertrand (2001) argue that human listeners are universally predisposed toward regularity in temporal processing. According to Jones and her colleagues (Drake, Jones, & Baruch, 2000; Jones, 1976, 1987; Large & Jones, 1999), listeners synchronize their internal oscillations to the external rhythm of auditory events while attending to *meaningful* rhythmic patterns. Internal oscillation is a periodic and self-sustaining process that creates expectancies about future events. When the rhythmic pattern is predictable, or has little variability in its periodicity, listeners generate expectations about the time of occurrence of subsequent events. The result is that attending is not only easy but also focused. In contrast, when sound sequences are irregular, with events occurring at unexpected times, greater attentional energy is required for synchronization because listeners must shift their locus of attention rapidly in the time dimension. For sound sequences with a very wide range of IOIs, the system has no attractor and cannot settle on a steady state of attention (Large & Jones, 1999).

Infants in the Nakata and Trehub (2004) study may have allotted more sustained attention to singing than to speech because of the greater ease of processing the regular temporal structure of singing than the fluctuating temporal structure of speech. It is possible then that the degree of temporal regularity of a stimulus is an important contributor to infants' attentional responsiveness. However, no studies have examined directly infants' preferences for sound sequences differing in regularity.

The purpose of the present study was to compare infants' attentional responsiveness to sound sequences that differed in temporal coherence. For this purpose, we adapted the preferential looking (listening) procedure used in previous research (Trainor, Tsang, & Cheung, 2002; Werker & McLeod, 1989). On each trial, one of two patterns (selected randomly) was presented to infants contingent on their fixation on a visual display. We predicted that regular sound sequences would be more effective than irregular sound sequences in sustaining attention among younger infants (6–8 months of age) and older infants (9–11 months of age). Following Jones (2001), attending to irregular sound sequences would be more cognitively demanding, and therefore should result in less attention from younger than from older infants. Younger infants were expected to listen longer to regular than to irregular sound sequences not only because of the lesser cognitive demands for listening to regular sequences but also because regularity plays an important role in younger infants' motor development (Thelen, 1981). It was possible that the preference might emerge in later test trials after stimulus novelty decreased, as in other studies with young infants (e.g., O'Neill, Trainor, & Trehub, 2001).

Method

PARTICIPANTS

The participants were 17 infants between 6 and 8 months of age (M = 224 days; range = 195–253 days; 7 boys and 10 girls) and 15 infants between 9 and 11 months of age (M = 307 days; range = 275–348 days; 11 boys and 13 girls) from the metropolitan area of Nagasaki City. All infants in the sample were healthy and free of colds at the time of testing. Moreover, no infant had a personal history of ear infections or a family history of hearing loss. The data from an additional 12 infants were excluded because of excessive fussing (n = 11) or failure to orient to the target visual display at the onset of a trial (n = 1).

APPARATUS

An iBook computer with a 12.1-inch (30.7 cm) screen was used to present auditory and visual stimuli. The digital sound files were played from the computer to a single multimedia speaker (Panasonic EAB-MPC301-S) placed directly behind the computer. A USB numerical keypad was connected to the computer and placed under the experimenter's table. White paper and cloth covered the computer and the experimenter's table to ensure that the only item visible to infants was the monitor and a puppet that was used to attract infants' attention immediately before each test trial.

STIMULI

Regular and irregular sound sequences were composed by joining 805-Hz, 21-ms xylophone-like tones created with the Praat analysis and synthesis program (Boersma & Weenink, 2002). Each sequence had a total duration of 30 s. The regular sound sequence had constant IOIs of 173 ms. The irregular sound sequence was created with variable IOIs. Each IOI was randomly selected from a square distribution (unit = 9.1 ms, min = 109 ms, max = 236 ms), with an average of 173 ms and standard deviation of 39 ms. Sound intensity level at the infants' ears was approximately 70 dB.

Although our sound sequences were faster than the optimal range of temporal processing for 2- and 4-month-olds (Baruch & Drake, 1997), they were within the range of IOI parameters used previously with infant listeners in the age range tested (e.g., Chang & Trehub, 1977).

PROCEDURE

We used a modification of the preferential looking procedure used by Trainor et al. (2002) and Werker and McLeod (1989). Specifically, infants' fixation of a visual display during the presentation of regular and irregular sound sequences was used as an index of their attentional preferences for these stimuli. Infants were tested individually in a quiet room at a child care facility. The infant sat on the lap of a female caretaker, facing the experimenter. The iBook computer was 45° to the left and approximately 90 cm from the infant. The experimenter maintained the infant's attention at midline by manipulating a small puppet on a table in front of her. She also held a keypad under the table to initiate trials and record responses. Both the caretaker and tester wore headphones delivering music to prevent them from hearing the sound sequences presented to infants.

When the infant was alert but calm and facing directly ahead, the experimenter pressed a button on a keypad, which initiated alternating red and black flashes on the monitor every 1/3 s. When the infant looked at the monitor, the experimenter pressed a second button that initiated one of the sound sequences as well as an image of a rectangle on a white background. The experimenter kept the second button depressed as long as the infant continued to look at the monitor. When the infant looked away for 2 s, the repeating sound sequence and image stopped and the screen became dark. Infants received 10 trials with regular sequences and 10 trials with irregular sequences in random order with the restriction that one type of sound sequence could not occur more than twice in a row.

Results

A preliminary analysis revealed that the sex of infants and the sound sequence presented first had no effect on visual fixation time. Accordingly, these two variables were excluded from subsequent consideration. For younger (6–8 months) and for older (9–11 month-old) infants, average looking times per trial were subjected to separate, 2-way repeated-measures analyses of variance, with sequence type (regular or irregular) and degree of familiarity (first five trials, last five trials) as within-subject factors. Analyses for the younger infants revealed a significant interaction between sequential type and familiarity, $F(1,16) = 4.67$, $p < .05$, $\eta^2 = .23$ (see Figure 1). Subsequent analyses revealed that for the first five trials, younger infants' average looking time per trial did not differ by type of sound sequence ($M = 2.54$ s, $SD = 1.04$ for regular; and $M = 2.73$ s, $SD = 1.51$ for irregular), $t(16) = 0.83$, $p > .05$. However, younger infants looked significantly longer while hearing regular ($M = 2.64$ s, $SD = 0.86$) than while hearing irregular ($M = 2.28$ s, $SD = 0.69$) sound sequences during the last five trials, $t(16) = 3.76$, $p < .01$. There were no significant main effects.

For the older infants, there was a significant main effect of familiarity, which indicated that looking time for regular and irregular sound sources decreased significantly from the first five trials ($M = 3.20$ s, $SD = 1.13$) to the last five trials ($M = 2.28$ s, $SD = 0.75$), $F(1,14) = 12.90$, $p < .01$, $\eta^2 = .69$. Younger and older infants' average looking time, combined for both regular and irregular sound sequences, did not differ for the first or the last five trials, *p*s > .05.

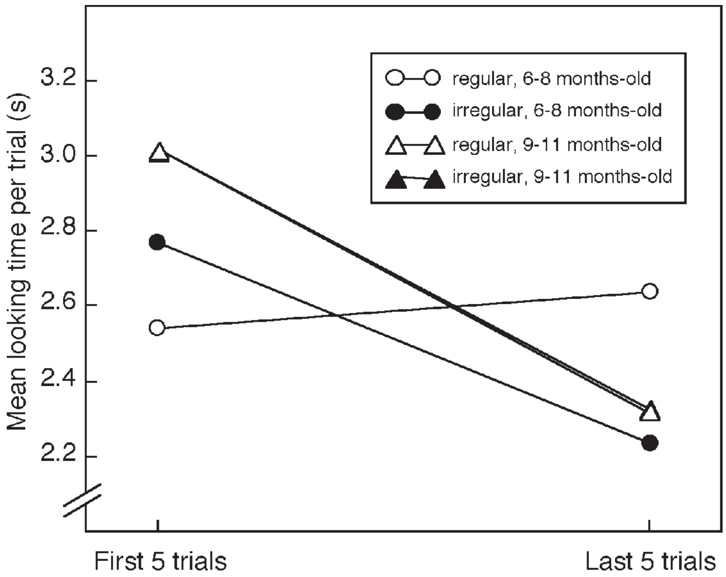

Fig. 1. Mean looking times (in seconds) to regular and irregular trials in infants 6–8 months old.

Discussion

The present experiment examined infants' attention to sound sequences as a function of the sequences' regularity of timing and relative familiarity. We predicted that regular sound sequences would be more effective than irregular sound sequences in maintaining infants' attention. Specifically, infants' attention over trials was expected to decrease more slowly for regular than for irregular sound sequences. We expected that a preference for regular sound sequences might emerge only during later trials when the novelty of the stimuli had waned. The results supported our predictions for infants who were 6–8 months of age but not for those who were 9–11 months of age. Younger infants displayed greater attention to regular than irregular sound sequences during the last five trials. Although older infants did not exhibit differential listening on the basis of sequence regularity, they showed less attention than younger infants to both types of sound from the first five trials to the last five trials.

Why did younger infants listen preferentially to the regular sound sequences and older infants show no preference? Although dynamic attending theory predicts greater ease of processing regular sound sequences (e.g., Jones, 2001; Large & Jones, 1999), it applies to meaningful sound sequences only. It is possible that lesser flexibility on the part of younger infants makes regularity in the external and internal environment more important for them than for older infants. As a result, regular sound sequences might be more meaningful for younger than older infants. Studies of motor development reveal the importance of regularity at around 6 months of age. Infants kick at regular intervals soon after birth, and kicking stereotypy peaks at about 6 months of age (Thelen, 1981). A central motor program is thought to be responsible for the regularity of kicking, which may prepare infants for subsequent walking (Thelen, 1981).

Caretakers seem to adapt intuitively to preverbal infants' need for regularity. For example, infant-directed speech is more stereotyped for younger than for older infants, with stereotypy peaking at about 4 months of age (Fernald & Simon, 1984; Kaplan, Goldstein, Huckeby, Owren, & Cooper, 1995; Papousek, Papousek, & Symmes, 1991; Stern, Spieker, & MacKain, 1982). When infants begin the process of learning language, stereotypy in infant-directed speech is reduced, allowing for greater complexity and variability. Recent research reveals that regular temporal structure, which is an important feature of music, may be effective for purposes of language instruction (Deckner, Adamson, & Bakeman, 2003). Specifically, rhythmic maternal vocalizations were associated with good infant language outcomes only when mothers matched infants' rhythmic vocalization. Frequent maternal rhythmic vocalizations were associated with low levels of infants' language measured several months later.

Preferences for temporal regularity or complexity may be related to physiological and social development. Gains in infants' cognitive and communicative skills lead to a shift in preferences from simple isochronous sound sequences to more complex sequences that contain more information. In the present study, the level of temporal cohesion in sound sequences was expressed by the standard deviation of IOIs. It is important to explore alternative means of expressing temporal complexity. A promising candidate for the expression of temporal complexity involves a family of random fractals known as fractal Brownian noises (Mandelbrot, 1977). Variability does not always translate to complexity. Greater information is contained in complex patterns expressed by fractal functions than by white noise. A variety of auditory (Voss & Clarke, 1978), visual (Keller, Crownover, & Chen, 1987), and motor phenomena (Schmidt, Beek, Treffner, & Turvey, 1991) have been described by fractal Brownian noises. For example, temporal patterns of human cortical activity closely follow tone sequence structure expressed by fractal functions (Patel & Balaban, 2000), but no such synchronization occurs when tone sequences are created by random functions. By expressing temporal complexity by fractal functions on a continuum, researchers will be able to evaluate various hypotheses about the relation between auditory temporal patterns and attention.[1]

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