2006

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Tonya R. Bergeson

Butler University, tbergeso@butler.edu

Sandra E. Trehub

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Recommended Citation

Bergeson, T. R., & Trehub, S. E. (2006). Infants' perception of rhythmic patterns. *Music Perception*, 23, 345-360.

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INFANTS' PERCEPTION OF RHYTHMIC PATTERNS

TONYA R. BERGESON AND SANDRA E. TREHUB
University of Toronto

WE EXPLORED 9-month-old infants' perception of auditory temporal sequences in a series of three experiments. In Experiment 1, we presented some infants with tone sequences that were expected to induce a strongly metric framework and others with a sequence that was expected to induce a weakly metric framework or no such framework. Infants detected a change in the context of the former sequences but not in the latter sequence. In Experiment 2, infants listened to a tone sequence with temporal cues to duple or triple meter. Infants detected a change in the pattern with duple meter but not in the pattern with triple meter. In Experiment 3, infants listened to a tone sequence with harmonic cues to duple or triple meter. As in Experiment 2, infants detected a change in the context of the duple meter pattern but not in the context of triple meter. These findings are consistent with processing predispositions for auditory temporal sequences that induce a metric framework, particularly those in duple meter.

Received October 8, 2004, accepted November 8, 2005

THE PERCEPTION OF REPETITIVE TIMING PATTERNS in sound or movement is critical because of its presumed contribution to interpersonal coordination or synchrony (Benzon, 2001; Trehub, 2003). Coordinated timing is especially apparent in infancy, for example, the rhythmic vocal and gestural interactions between mothers and infants (Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001) and the disruptions precipitated by breakdowns in communicative rhythms (Nadel, Carchon, Kervella, Marcelli, & Réserbat-Plantey, 1999). The environment of prelinguistic infants is replete with rhythmic sound events, including speech and songs (Bergeson & Trehub, 2002; Fernald, 1991; Trehub & Trainor, 1998), which are effective in capturing and maintaining infant attention (Fernald, 1985; Masataka, 1999; Nakata & Trehub, 2004; Trainor, 1996).

When adults listen to auditory sequences such as musical pieces, they organize the input in terms of grouping structures and metric structures (Lerdahl & Jackendoff, 1983). *Grouping* describes the organization of sounds into coherent units on the basis of their similarity and temporal proximity (Bregman, 1990; Deutsch, 1999). Upon hearing the song "Twinkle, Twinkle," for example, adults may consider the first phrase "Twinkle, twinkle, little star" as one group and the second phrase "how I wonder what you are" as another. *Meter* describes the pattern of strong and weak beats within a temporal sequence (Clarke, 1999). Adults might perceive strong beats on the first of every two syllables, as in "Twinkle, twinkle, little star . . . , how I wonder what you are." Note that grouping and meter can occur independently of *tempo*, or musical speed (London, 2005).

The available information indicates that infants group auditory events in much the same way as adults. For example, Demany, McKenzie, and Vurpillot (1977) documented 2- to 3-month-old infants' differentiation of isochronous (i.e., equally timed) sequences from rhythmic sequences, and Chang and Trehub (1977) documented 5-month-olds' differentiation of contrasting rhythmic groupings (e.g., xx xxxx versus xxxx xx). Trehub and Thorpe (1989) showed that 7- to 9-month-olds could categorize tone patterns on the basis of their grouping even when tempo and frequency varied across instances. For example, infants differentiated tone groupings of xx xx from xxx x (i.e., 2-2 vs. 3-1) regardless of the tempo and tone frequency of the patterns. Trainor and Adams (2000) exposed 8-month-old infants to sequences of two short tones (S) followed by a long tone (L). The sequences had a silent gap between the two short tones (SgSL), between the short and long tones (SSgL), or after the long tone (SSLg). Infants detected gaps more readily in the first two conditions, which disrupted the original grouping structure, than in the last condition, which was consistent with the original structure. The aforementioned studies indicate that infants are sensitive to temporal grouping properties, as described by the Gestalt law of proximity, which holds that tones in temporal proximity are grouped into coherent units.

Morrongiello (1984) investigated age-related changes in the fine-tuning of these grouping processes. She

tested infants on their ability to detect changes in the number of groups in a nine-tone sequence (e.g., 3-3-3 vs. 5-4) and in the number of elements per group (e.g., 3-3-3 vs. 2-5-2). Although 12-month-olds detected changes in the number of groups and in the number of elements per group, 6-month-olds only detected changes in the number of groups.

These studies involve rhythmic grouping processes, which may contribute to the perception of accents and beat structure in temporal patterns (e.g., Essens & Povel, 1985; Povel, 1981, 1984; Povel & Essens, 1985). A rhythmic sequence is presumed to induce an internal clock based on the distribution of accented events in the sequence (Povel & Essens, 1985). For example, a perceptual accent occurs on the first and last event of a group of three or more events, on the second event of a pair of events, and on isolated events in time. Just as the units of a ruler or clock are equal intervals that can be subdivided or concatenated hierarchically, a temporal sequence can be divided into equal units, or beats. In the song "Jingle Bells," the first phrase consists of two groups of three notes (see Figure 1). Because perceptual accents occur on the first and last events of a group of events, accents are heard on the first and last notes of each group in the current case (i.e., the syllables "Jin-" and "bells"). Note that the accents coincide regularly with clock units at the beat level. These accents are considered to define the beat or tactus (Lerdahl & Jackendoff, 1983), which corresponds to the usual pattern of tapping while singing or listening to music. These clock units can be subdivided (*note* level) or concatenated (*measure* level) to create a temporal hierarchy.

Whereas the distribution of accents, or the number of beats that coincide with an accented event, forms the basis of the internal clock, the number of beats that coincide with silence (i.e., the absence of events) contributes to the relative strength of the internal clock

(Povel & Essens, 1985). Specifically, a temporal sequence in which accented events are not regularly distributed in a metric hierarchy may not induce an internal clock, or it may induce a relatively weak internal clock. For the purposes of the present study, temporal patterns that induce an internal clock were considered *strongly metric*, whereas those that induce a weak internal clock were considered *weakly metric* (following Essens & Povel, 1985). Presumably, the presence of an internal clock facilitates the organization of an auditory temporal sequence, which should enhance cognitive processes such as recall. Regardless of their music training, adults reproduce strongly metric rhythms more accurately than weakly metric rhythms (Essens, 1986, 1995; Essens & Povel, 1985; Povel & Essens, 1985). Moreover, highlighting the beat or clock enhances the reproduction of rhythms (Drake, 1993; Povel & Essens, 1985). Adults also discriminate subtle timing changes more readily when the rhythms induce strong metric clocks than when they induce weak metric clocks, particularly when the tone durations exceed 200 ms (Handel, 1998; Hébert & Cuddy, 2002; Ross & Houtsma, 1994).

The internal clock model of rhythm perception is similar in some respects to Dynamic Attending Theory (e.g., Drake, Jones, & Baruch, 2000; Jones & Boltz, 1989), which holds that the physical characteristics of a temporal sequence and the regular occurrence of prominent markers, or accents, determine the referent level (corresponding to the internal clock). Listeners are thought to "attune" to rhythms and become "phase-locked" to corresponding time spans that are marked or accented within the sequence. This process is likely to occur with temporally coherent events such as metric rhythms. By contrast, failed attunements involve an asynchrony between the rhythm and the referent level, as in the case of nonmetric rhythms.

According to Drake (1998), listeners' ability to extract regularity in temporal patterns is universal, generalizing across culture, age, and levels of music experience. For example, 5- and 7-year-olds have less difficulty reproducing patterns with simple rhythms (i.e., those with a regular beat) than those with complex rhythms (Drake & Gérard, 1989). Children's performance improves when the beat or clock is highlighted in such rhythms (Drake, 1993), which parallels adults' performance (e.g., Essens & Povel, 1985; Povel & Essens, 1985). Moreover, children can synchronize their tapping with musical sequences by 5 years of age (Dowling, 1984; Drake, 1997). Not surprisingly, 7-, 9-, and 11-year-olds have more difficulty with syncopated than with synchronized finger tapping (Volman & Geuze, 2000).

FIG. 1. Metric structure for the song "Jingle Bells." Durations are shown in ms.

Specifically, children can tap along with a metronome, but they experience difficulty when required to tap between the metronome pulses, or "off" the beat.

Temporal regularity may enhance infants' perception of auditory sequences, accounting, perhaps, for 2-month-olds' differentiation of isochronous sequences with slightly different tempi (Baruch & Drake, 1997) and their differentiation of isochronous from non-isochronous sequences (Demany et al., 1977). It may also facilitate infants' detection of tempo changes (Pickens & Bahrick, 1995). If humans are predisposed or "hardwired" to extract regularity from temporal sequences (Drake, 1998), then infants may be able to distinguish temporal sequences that induce an internal clock (strongly metric rhythms) from those that do not (weakly metric rhythms).

Experiment 1

The purpose of the present experiment was to explore the possibility of differential processing of strongly metric and weakly metric rhythms by 9-month-old infants. Infants heard repetitions of one of the four temporal sequences depicted in Figure 2. The subjectively accented events in the sequence are marked by the "greater-than"

(>) symbol. Although tones marked with accents were presented at the same intensity as nonaccented tones, they were expected to be perceived as accented because they met Povel and Essens' (1985) criteria for accented events. In the case of the strongly metric rhythms, all accented tones were aligned with a beat. Only one of the beats in the Strong A pattern coincided with an unaccented note, and none of the beats in any of the strong metric patterns coincided with empty intervals (i.e., silence). The strongly metric rhythms were expected to induce an internal clock by virtue of the temporal regularity of accents. In the case of the weakly metric rhythm, only two beats coincided with accented notes, one beat coincided with an unaccented note, and two beats coincided with empty intervals. This distribution of accented notes should be less than optimal for inducing an internal clock.

Infants were trained to turn toward the sound source in response to a change in the pattern (following Trehub & Thorpe, 1989). We predicted that infants would detect a subtle temporal change (i.e., 100-ms change in one tone) more readily in the context of a strongly metric rhythm than in the context of a weakly metric rhythm. Specifically, the strongly metric rhythm was expected to generate an internal clock, which would

FIG. 2. Examples of metrically strong and weak rhythms. Durations are shown in ms.

facilitate its encoding and, in turn, the detection of temporal changes.

Method

Participants. The participants were 64 healthy, full-term infants who were 8;6 to 9;6 months of age ($M = 8;11$ months) and whose families volunteered in response to letters distributed in the community. None of the infants had colds or ear infections on the day of testing, nor did they have a family history of hearing problems. An additional 58 infants were excluded from the final sample because of (a) failure to meet the training criterion ($n = 40$), (b) failure to complete the test session ($n = 6$), or (c) fussiness, restlessness, or parental interference during the test session ($n = 12$). High infant attrition rates such as these are typical in the context of sequences of unvarying pitch.

Apparatus. Testing took place in a double-wall sound-attenuating booth (Industrial Acoustics) with an ECS computer controlling stimulus presentation and recording responses. The stimuli were generated online by two tone generators (Hewlett-Packard 3325A) and presented by means of a stereo amplifier (Marantz 1060), loudspeaker (Avant 2AX), and two attenuators (Med Associates). The experimenter initiated trials and recorded responses with a customized button box connected to the computer. To the infant's left, a four-chamber smoked Plexiglas box under the loudspeaker contained four different mechanical toys, one of which was illuminated and activated automatically (in random order) when the infant responded correctly. The loudspeaker was located to the infant's left because of rightward biases in head turning (e.g., Bourne & Todd, 2004; Mount, Reznick, Kagan, Hiatt, & Szpak, 1989; Ronquist, Hopkins, van Emmerik, & de Groot, 1998).

Stimuli. The rhythmic patterns, which are shown in Figure 2, were sequences of seven pure tones, all at identical pitch level. The tones of each pattern were all either C# (277 Hz), F# (370 Hz), or G# (415 Hz). Successive repetitions of the standard pattern were transposed to closely related keys in the circle of fifths (Kostka & Payne, 1989), resulting in an overall tonal pattern. The eighth (short) notes were 250 ms in duration, followed by 50 ms of silence. The quarter (long) notes were 500 ms in duration, followed by 100 ms of silence. Thus, the total duration of each rhythmic pattern was 3.6 s. The duration of the silent interval following each pattern was 450 ms, which interrupted the experience of the "beat." Thus, listeners would be required to readjust their internal clock with every presentation of the pattern. There were four conditions: *Strong A*, *Strong B*,

Strong C, and *Weak*. Each infant was tested in only one of these conditions. In each condition, there was a standard pattern and a comparison pattern that differed from the standard by a 100-ms decrease in duration on the third (*Strong B*, *Strong C*), fourth (*Weak*), or fifth (*Strong A*) note. Although the change occurred on different notes in the four conditions, the duration decrease fell on a long note following a group of shorter notes (i.e., on an accented note) in all conditions.

Accented notes could occur according to three grouping rules: (a) isolated notes, (b) the second note in a group of two notes, and (c) the first and final notes in a group of three or more notes (e.g., Povel & Essens, 1985). The *Strong A* and *Weak* rhythms contained four accented notes and three unaccented notes. In the *Strong A* rhythm, all four accented notes were aligned with beats in the temporal framework. Only one of the beats occurred with no accent, but this beat still coincided with the occurrence of an unaccented note. In the *Strong B* and *C* rhythms, all five accented notes were aligned with beats in the temporal framework. In the *Weak* metric rhythm, two accented notes were aligned with beats in the temporal framework, two additional accented notes occurred "off" the beat, two beats occurred in the absence of a note, and one beat coincided with an unaccented note. In line with Povel and Essens' (1985) framework, the *Strong* rhythms should induce robust internal clocks, in contrast to the *Weak* rhythm, which should induce a weak internal clock, at best.

Procedure. Four groups of 16 infants were tested in one of the four conditions in a between-subjects design. Infants sat on their parent's lap directly facing the experimenter in the sound-attenuating booth. The loudspeaker and toys were located 45° to their left. The parent and the experimenter wore headphones to preclude the audibility of change and no-change trials. Infants were presented with the repeating standard tone sequence separated by 450-ms silent intervals. Each presentation of the standard (and comparison) sequence was transposed relative to the preceding and following sequence.

The experimenter used puppets and other toys to attract and maintain infants' attention at midline. When the infant was facing directly ahead, the experimenter pressed a button on the button box to signal (to the computer) the infant's readiness for a trial. A training phase preceded the test phase to familiarize infants with the procedure, specifically with the visual rewards that were contingent on responses to changes in the repeating auditory sequence. During the training phase, the initial comparison sequences were presented at an

intensity 5 dB greater than the preceding standard sequence. The comparison sequence during the training phase also incorporated a change that was much larger than that used in the test phase. Specifically, the change involved a tone decreased by 300 ms and the following tone replaced by a silent interval (fifth tone for Strong A, third tone for Strong B and C, and fourth tone for the Weak pattern) compared to the 100-ms decrease in the test phase. If the infant turned toward the loudspeaker, the experimenter pressed another button on the button box. The computer recorded turns that occurred within 3 s after the onset of a potentially changed tone. Correct turns that occurred within 3 s of a change led to the illumination and activation of one of the four mechanical toys for 2 s. Turns at other times had no consequence. After the infant responded correctly to two consecutive training trials, all subsequent trials had standard and comparison patterns presented at equal intensity (75 dBA). Infants were required to meet a training criterion of four consecutive correct trials without intensity cues. Testing was terminated if infants became fussy or if they failed to meet the training criterion within 30 trials.

Once the training criterion was met, the test phase began. As before, the experimenter indicated the infant's readiness for a trial (i.e., looking directly ahead) by pressing a button on the button box. On such occasions, infants received one of two types of trials: *change* trials, consisting of a single comparison pattern, and *no-change* trials, consisting of another repetition of the standard pattern. The computer presented trials only if the infant was looking directly ahead and at least two repetitions of the standard pattern had occurred since the preceding trial. The test phase consisted of 24 trials, 12 change and 12 no-change, in pseudorandom order, with the constraint that only two no-change trials could be presented consecutively.

Results and Discussion

The data consisted of mean numbers of hits (head turns on change trials) and false alarms (head turns on no-change trials) for each condition (see Table 1). The data were transformed to discrimination (d') scores for each infant using yes/no tables from signal detection theory (Elliott, 1964). Because the small numbers of trials (12 change, 12 no-change) can result in perfect hit rates (12 out of 12) or false-alarm rates (0 of 12), leading to infinite d' scores, 0.5 was added to the number of infant responses on change and no-change trials, and 1.0 to the total number of trials (see Thorpe, Trehub, Morrongiello, & Bull, 1988). This correction does not

TABLE 1. Mean number of hits and false alarms in experiment 1, 2, and 3.

	Hits	False alarms
Experiment 1		
Strong A	6.5 (1.2)	3.3 (1.7)
Strong B	5.8 (2.0)	3.0 (1.7)
Strong C	5.2 (2.3)	3.2 (1.2)
Weak	3.7 (1.5)	2.9 (1.1)
Experiment 2 (temporal cues)		
Duple meter	6.8 (1.9)	3.5 (2.3)
Triple meter	4.7 (2.2)	3.3 (1.2)
Experiment 3 (harmonic cues)		
Duple meter	6.3 (2.6)	3.7 (2.0)
Triple meter	3.9 (2.5)	3.9 (1.6)

Note. Standard deviations are in parentheses. A perfect score would consist of 12 hits and 0 false alarms.

alter the rank order of scores. Note that an equal number of head turns on change and no-change trials produces a d' of 0, or chance performance.

One-sample t tests revealed that infants performed significantly better than chance when the standard pattern was strongly metric, as in Strong A, $t(15) = 6.77$, $p < .0001$; Strong B, $t(15) = 4.04$, $p < .01$; and Strong C, $t(15) = 3.42$, $p < .01$ (see Figure 3). By contrast, their performance was at chance levels in the context of the Weak metric rhythm, $t(15) = 1.96$, n.s. Moreover, a univariate Analysis of Variance with one between-subjects independent variable (rhythm condition: Strong A, Strong B, Strong C, and Weak) revealed a main effect of rhythm condition, $F(3, 60) = 3.85$, $p < .05$. Performance was significantly better in two of the Strong rhythms than in the Weak rhythm, Strong A versus Weak, $t(30) = 3.79$, $p < .001$; and Strong B versus Weak, $t(30) = 2.51$, $p < .05$. A one-tailed t test also revealed marginally significant performance differences between the Strong C and Weak rhythms, $t(30) = 1.55$, $p = .07$.

The results indicate that infants attended to the distribution of accented notes for the strongly metric rhythms, but not for the weakly metric rhythm. Infants' pattern of performance parallels adults' reproduction of metrically strong and weak temporal sequences (Essens & Povel, 1985; Hébert & Cuddy, 2002; Povel & Essens, 1985; Ross & Houtsma, 1994). Proponents of Dynamic Attending Theory (Large & Jones, 1999) argue that changes to notes on strong beats should be easier to detect than changes to notes on weak beats, regardless of whether the notes are accented or unaccented. Thus, definitive interpretation of these findings must await further research. In view of infants' relative inexperience with temporal sequences such as those found in music, the findings are consistent with the view that

FIG. 3. Mean discrimination (d') scores for Experiment 1 as a function of the metric structure (strong or weak) of the standard pattern. Error bars indicate standard errors.

extracting temporal regularity or inducing an internal clock from auditory temporal sequences (particularly metric rhythms) is a universal process (Drake, 1998).

Why were the performance differences between the Strong C and Weak rhythms only marginally significant? In a revision of the original clock model of rhythm (Essens & Povel, 1985; Povel & Essens, 1985), Essens (1995) introduced the notion of a *figural envelope*. Essentially, groups of tones that occur in a temporal sequence are naturally shaped by the internal clock or the location of the beat. Variations in the relations among groups and beats may violate listeners' expectations. After hearing a group of three notes that starts on a beat, subsequent groups of notes may be expected to start on the beat rather than preceding or spanning it. In fact, Essens (1995) found that variations in the relations between groups of tones and the beat structure, or internal clock, were correlated with adults' ratings of the complexity of temporal sequences.

Although the Strong C rhythm in the present study induced an internal clock of similar strength to the Strong A and Strong B rhythms, infants' performance in the Strong A and B rhythm conditions significantly exceeded their performance in the Weak rhythm condition of Experiment 1, but their performance in the Strong C rhythmic condition did not. This finding could stem from the fact that the two groups of tones did not start on strong beats in the hierarchical metric framework. Instead, the second group of tones spanned a strong beat. Alternatively, the grouping structure may suggest an incomplete triple meter, with the beginning of each

group of tones occurring on the strong first beat. Moreover, triple meter may be more difficult for infants to process than duple meter. Nevertheless, infants performed above chance levels in the Strong C rhythmic condition but not in the Weak rhythmic condition. Our findings are consistent with the notion that the alignment of beat structure and temporal sequences is unstable in very young children (Drake, 1997; Drake et al., 2000).

All of the rhythmic patterns in the present experiment could be considered to be in duple meter, which involves the subdivision of each measure into two beats, in contrast to triple meter, which involves a subdivision into three beats. In Western classical music, approximately 80-90% of note durations are in a 2:1 ratio (Fraisse, 1978), and these durations are often combined in binary groups (i.e., duple meter). Lerdahl and Jackendoff (1983) suggest that listeners show preferential processing of relations between hierarchical levels of a metric structure related by 2:1 rather than 3:1 ratios. A preference for binary structures may arise because of their prevalence in music in the Western European tradition. Alternatively, the occurrence of binary structures in many musical cultures may arise from processing predispositions for 2:1 ratios. Indeed, Essens and Povel (1985) and Fraisse (1982), among others, argue for "natural" or inherent preferences for binary over ternary relations, but their evidence is based largely on adults with Western music exposure.

Research on rhythm production and imitation is consistent with the "natural" hypothesis. For example, 5- to 7-year-olds reproduce musical rhythms more accurately

when those rhythms incorporate binary rather than ternary metrical subdivisions (Drake, 1993). Drake (1997) argues, however, that 2:1 and 3:1 ratios are more easily conceptualized than are other ratios. She asked 6- to 8-year-olds and adult nonmusicians to tap synchronously with isochronous auditory sequences that had no accents or that had intensity accents on every second, third, fourth, or fifth note. When the participants were asked to tap faster than required for direct synchronization (i.e., to subdivide the beats), they produced binary subdivisions more frequently than ternary subdivisions. When asked to tap slower than required for direct synchronization (i.e., necessitating metric organization), children and adults synchronized equally well with binary and ternary accents. Moreover, they showed no preference for binary over ternary synchronizations. Such binary and ternary metric organization is similar to the music terms *duple* and *triple* meter. Each measure, which was marked by accented notes, could be divided into two or three beats. Thus, Drake's (1997) findings imply that children and adults prefer binary subdivisions of the beat, but they do not prefer duple to triple meter.

There are indications, however, that meter (duple vs. triple) is highly salient for adults (Gabrielsson, 1973; Monahan & Carterette, 1985), and that it may be salient for 7-month-old infants (Hannon & Johnson, 2005; Phillips-Silver & Trainor, 2005). Adult musicians and nonmusicians notice pitch alterations more quickly for melodic sequences in duple meter rather than triple meter, even when the harmonic structure implies triple meter (Smith & Cuddy, 1989). When adults are required to identify the meter of auditory sequences, they exhibit a bias for duple meter whether harmonic, melodic, and temporal cues support or conflict with triple meter (Dawe, Platt, & Racine, 1994; Vos, van Dijk, & Schomaker, 1994). Some musically trained children notate the grouping and metric structure of rhythms in duple meter, but they fail to consider the metric structure of rhythms in triple meter (Upitis, 1987). Perhaps the children in Drake's (1997) study could synchronize with duple and triple meters because they followed the intensity accents in the isochronous temporal sequences. The detection of pitch changes or the categorization of metric structure may be more difficult in rhythmic sequences that are more musical. In fact, on-beat tapping tends to be less difficult than off-beat tapping at the same rate (e.g., Fraisse, 1978; Volman & Geuze, 2000). In short, measures of reaction time, rhythm categorization, and notation in children and adults are consistent with processing predispositions for duple over triple meter.

Experiment 2

Our motivation for investigating infants' perception of duple and triple meter was to determine whether listeners with minimal music experience exhibit the bias for duple meter that is evident in adults and older children (Dawe et al., 1994; Smith & Cuddy, 1989; Upitis, 1987). We presented 9-month-old infants with a melodic sequence in which the temporal structure of the tones implied duple or triple meter (see Figure 4). Each measure in the duple-meter pattern was divided into two beats, and each measure in the triple-meter pattern was divided into three beats. The strongest accents (i.e., longest tone durations) signaled the beginning of each measure. Infants were trained to turn to the sound source when they heard a change in the pattern. If duple meter is inherently easier to encode than triple meter, then infants should detect subtle pitch changes more readily for melodic patterns in duple meter than in triple meter.

Method

Participants. The participants were 32 healthy, full-term infants 8;6 to 9;7 months of age ($M = 9;0$ months) whose families volunteered in response to letters distributed in the community. None of the infants had colds or ear infections at the time of testing, nor did they have a family history of hearing problems. An additional 24 infants were excluded from the final sample because of (a) failure to meet the training criterion ($n = 14$), (b) failure to complete the test session ($n = 3$), or (c) fussiness, restlessness, or parental interference during the testing session ($n = 7$).

Apparatus. The equipment was identical to that of Experiment 1.

Stimuli. Rhythmic patterns from the present study are shown in Figure 4. The patterns were sequences of 10 pure tones, with the same melody in each condition. The duration of a measure in each pattern was 1.2 s, with each pattern consisting of four measures (separated by vertical lines in the figures). There were two conditions: *duple* and *triple* meter. The measure was divided into two beats in the duple-meter condition and into three beats in the triple-meter condition. In the duple-meter condition, the longer tones were 600 ms, and the shorter tones were 300 ms. The total duration of the duple-meter pattern, including the silent interval following the last note (600 ms), was 4.8 s. In the triple-meter condition, the longer tones were 800 ms, and the shorter tones were 200 ms. The total duration of the triple-meter pattern, including the silent interval following the last tone

FIG. 4. Examples of duple and triple meter implied by temporal cues. Durations are shown in ms.

(400 ms), was 4.8 s. Both pattern types involved binary subdivision of the beat (i.e., the last beat of the measure was subdivided into two eighth notes). For each condition, the comparison pattern differed from the standard by a one-semitone pitch change (upward) on the third tone, which was highest in pitch (e.g., from A to A#). The pitch change occurred on a metrically weak but melodically strong tone in both rhythmic patterns.

Procedure. The procedure was identical to that of Experiment 1 with the following exceptions. The standard tone sequence was presented repeatedly, with repetitions separated by 600-ms (duple meter) or 400-ms (triple meter) silent intervals. Successive repetitions of the standard pattern were presented in transposition to closely related keys (Kostka & Payne, 1989). The first tone of each pattern was D (294 Hz), G (392 Hz), or A (440 Hz). The comparison sequence in the training phase incorporated a change that was much larger than that used in the test phase. The third tone of each pattern was increased in pitch by five semitones rather than the one-semitone change in the test phase.

Results and Discussion

The data, which consisted of the mean numbers of hits (head turns on change trials) and false alarms (head turns

on no-change trials) for each condition (see Table 1), were transformed to d' scores, as in Experiment 1. One-sample t tests revealed that infants performed significantly better than chance in the duple-meter condition ($M = 0.74$, $SD = 0.69$), $t(15) = 4.26$, $p < .001$, and in the triple-meter condition ($M = 0.29$, $SD = 0.36$), $t(15) = 3.23$, $p < .01$ (see Figure 5). Moreover, performance was significantly better in the duple-meter condition than in the triple-meter condition, $t(30) = 2.28$, $p < .05$. Thus, the pattern in duple meter seemed easier to encode than the pattern in triple meter, which is consistent with the notion of processing predispositions for duple meter.

Although the same melodic sequence was used for both types of meter, the duration changes necessary to induce duple versus triple meter could have influenced infants' performance. For example, the change always occurred on a short tone, which was shorter in the triple-meter pattern (200 ms) than in the duple-meter pattern (300 ms). It is possible that the longer tone duration enhanced the salience of the target change. Moreover, the durations of tones in the duple-meter pattern were in a 2:1 ratio (600:300 ms), as compared with a 4:1 ratio in the triple-meter pattern (800:200 ms), generating a potential bias for duple meter. Although the overall duration (4.8 s) and number of measures (4) were identical for both conditions, there were fewer

FIG. 5. Mean discrimination (d') scores for Experiments 2 and 3 as a function of the metric structure (duple or triple meter) of the standard pattern. Error bars indicate standard errors.

beats in the duple-meter pattern (i.e., 8) than in the triple-meter pattern (i.e., 12). If memory for rhythmic patterns is affected by the number of underlying pulses rather than the actual auditory elements, as Drake and Gérard (1989) suggest, then the duple-meter pattern would be easier to encode than the triple-meter pattern. According to Povel and Essen's (1985) internal clock model, the triple-meter pattern would not induce an internal metric clock as strongly as would the duple-meter pattern. The same numbers of grouping accents coincide with beats in each pattern, but an unfilled interval is aligned with the second beat in the triple meter. Infants may be sensitive to the relative strength of the patterns rather than, or in addition to, the type of meter. Thus, it was prudent to provide converging evidence by determining whether infants would exhibit a bias for duple meter when presented with melodic sequences in which meter is signaled by harmonic changes rather than by duration changes.

Experiment 3

To date, there has been little research on the use of harmonic cues to metric structure. Dawe et al. (1993, 1994) had adult musicians and nonmusicians listen to auditory temporal sequences and identify either the rhythmic pattern (i.e., groups of long and short notes) or

the type of meter (duple or triple). The sequences were constructed so that harmonic, melodic, and temporal accents were pitted against one another. The results revealed that harmonic accents made the greatest contribution to listeners' categorization of rhythm and meter, with musicians using harmonic information more often than nonmusicians. A preference for duple over triple meter was also apparent (Dawe et al., 1994). Smith and Cuddy (1989) found that adults were much slower to detect pitch alterations in triple than in duple meter, particularly when the harmonic and dynamic accents were aligned. Although the available research indicates that young children have limited implicit knowledge of harmony (Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Speer & Meeks, 1985; Trainor & Trehub, 1994), no studies have explored children's use of harmonic cues to metric structure.

There is evidence that pitch structure affects temporal pattern perception in infancy (Thorpe et al., 1988; Trehub & Thorpe, 1989). Thorpe and Trehub (1989) presented 6- to 9-month-old infants with a sequence of six tones of equal duration, the first three tones being identical in pitch and the last three being higher or lower in pitch but identical to one another. Infants detected 100-ms tone increments more accurately when they occurred within a tone group (e.g., xxxo oo) than between tone groups (e.g., xxx ooo), indicating that

infants had grouped the tones on the basis of pitch level. Although Trainor and Trehub (1994) found no evidence that infants were sensitive to implied harmony, it is possible that harmonic cues could affect infants' perception of meter.

In the present experiment, infants heard a melodic sequence that had harmonic cues to duple or triple meter (see Figure 6). Harmonic changes on the strong beats signaled a new measure, with each measure divided into two or three equally timed beats. As shown in Figure 6, both melodic sequences had similar underlying harmonic progressions (essentially tonic-dominant-tonic, or I V I V I), the same melodic contour (rising-falling-rising-falling), and the same component pitches (e.g., B3, C4, D4, E4, F4, G4). Although each measure was shorter in the duple-meter version (800 ms) than in the triple-meter version (1200 ms), the duple-meter pattern had more tones (11) and measures (6) than did the triple-meter pattern (10 tones, 4 measures). If infants are capable of using harmonic cues to meter and if duple meter, as implied by harmonic cues, is inherently easier to encode than triple meter, then infants should detect changes to the duple-meter pattern more easily than comparable changes to the triple-meter pattern. On the basis of the available evidence (e.g., Dawe et al., 1994; Smith &

Cuddy, 1989), we expected infants to detect a subtle (one-semitone) pitch change more readily in the context of duple meter than in triple meter.

Method

Participants. The participants were 32 healthy, full-term infants 8;6 to 9;5 months of age ($M = 8;10$ months) whose families volunteered in response to letters distributed in the community. None of the infants had colds or ear infections at the time of testing, nor did they have a family history of hearing problems. An additional 27 infants were excluded from the final sample because of (a) failure to meet the training criterion ($n = 17$), (b) failure to complete the testing session ($n = 5$), or (c) fussiness, restlessness, or parental interference during the test session ($n = 5$).

Apparatus. The equipment was identical to that of Experiment 1.

Stimuli. Rhythmic patterns used in the present study are shown in Figure 3. The patterns were sequences of 10 or 11 pure tones. There were two conditions: *duple* meter and *triple* meter. The measure (bounded by vertical lines in the figures) was divided into two beats in the duple-meter condition and into three beats in the triple-meter condition. All tones in each condition were 400 ms, except for the final tones, which were 800 ms. The total duration was 4.8 s in the duple-meter condition and 4.4 s in the triple-meter condition. In each condition, the comparison pattern differed from the standard pattern by a one-semitone pitch decrease on the sixth tone, which was lowest in pitch (e.g., from B to Bb).

Procedure. The procedure was similar to that of Experiment 2, with the following differences: (a) the to-be-detected change in the training phase was a 15-semitone increase in pitch (1 octave + 3 semitones) on the sixth tone, (b) infants were presented with repeating standard sequences separated by 800-ms (duple meter) or 400-ms (triple meter) silent intervals, and (c) successive repetitions of the standard pattern were presented in transposition, with the first tone of each pattern being C (262 Hz), F (349 Hz), or G (392 Hz).

Results and Discussion

The data, which consisted of mean numbers of hits (head turns on change trials) and false alarms (head turns on no-change trials) for each condition (see Table 1), were transformed to d' scores, as in Experiment 1. One-sample t tests revealed that infants performed significantly better than chance only in the duple-meter condition

FIG. 6. Examples of duple and triple meter implied by harmonic cues (harmonic progression depicted by Roman numerals). Durations are shown in ms.

($M = 0.55$, $SD = 0.54$), $t(15) = 4.11$, $p < .001$ (see Figure 5). Moreover, performance was significantly better in the duple-meter condition than in the triple-meter condition ($M = -0.04$, $SD = 0.63$), $t(30) = 2.86$, $p < .01$. Thus, not only do infants distinguish duple meter from triple meter, but they seem to use implied harmonic cues to do so. This is the first study to suggest implicit knowledge of harmony on the part of infants. Young school-age children, as noted above, may have an implicit knowledge of harmony, but no previous studies, to our knowledge, have shown that infants or preschool children have an understanding of harmony. Perhaps infants who are capable of using broad harmonic categories in melodies that unfold over time would be incapable of making finer harmonic distinctions. Finally, superior performance in the duple-meter condition with temporal and harmonic cues provides converging evidence for a processing predisposition for binary relations between events.

General Discussion

Infants detected changes more readily in the context of strongly metric rhythms than in the context of weakly metric rhythms. Specifically, they detected 100-ms increments in the strongly metric rhythms despite variations in grouping structure. They extracted the regularity in accents at the beat level and used this structure to detect subtle temporal changes. Moreover, infants detected subtle pitch changes in melodic sequences more readily when the sequences were in duple meter rather than triple meter, regardless of whether the meter was implied by temporal cues (Experiment 2) or by harmonic cues (Experiment 3). The results are consistent with predispositions for temporal patterns that induce a metric framework. They are also consistent with claims of natural preferences for binary hierarchical structures (e.g., Essens & Povel, 1985; Fraisse, 1982; Povel, 1981). The findings lend credence to the view that binary relations between events are prevalent in music because of fundamental perceptual preferences for such relations. The notion is that artists intuitively consider perceptual principles when composing poetry or music (Fraisse, 1982).

Infants' superior performance on strongly metric than on weakly metric rhythms implies that they perceived some accented tones, in line with the metric framework. They may have extracted regularity from accented events in the context of the strongly metric rhythms but not in the context of the weakly metric rhythm. The major difference between the two types of

rhythms was the greater regularity of accented events in the strongly metric rhythm than in the weakly metric rhythm. Presumably, regular accents promote the induction of an internal clock that facilitates encoding of the temporal sequence and, consequently, the detection of subtle (100-ms) changes. If infants organized the weakly metric rhythm in terms of tone groups, that would not have facilitated detection of the 100-ms change. If the change resulted in a new grouping pattern, infants might have detected the change in both conditions.

The weakly metric rhythm was not without structure. Its long tones were always twice the duration of its short tones, and each tone coincided with a unit at the note level, a subdivision of the beat (see Figure 2). In other words, these sequences were not arrhythmic by any means. Chance performance like that obtained in the weakly metric condition would also be expected for arrhythmic sequences. Drake and Gérard (1989) found no differences in performance on the part of 5- and 7-year-olds for complex rhythmic patterns, simple arrhythmic patterns, or complex arrhythmic patterns. Thus, the irregular distribution of accented events seems to disrupt the perception of temporal sequences to the same extent as do arrhythmic patterns.

The initially loose coupling between units of the internal metric framework and the external temporal sequences is strengthened with age and music training, with corresponding improvements in the ability to synchronize tapping with such temporal sequences (Drake et al., 2000). As Drake et al. (2000) found, however, rich musical pieces make it possible for young children and nonmusicians to synchronize their tapping in ways that they are unable to do with the impoverished isochronous or rhythmic sequences of most laboratory studies. In principle, highlighting the beat level through melodic cues could affect infants' perception of weakly metric or nonmetric rhythms.

Although efficient processing of duple meter may be a perceptual primitive, comparable processing of triple meter may require experience with music unless the music is accompanied by synchronous body movement (Phillips-Silver & Trainor, 2005). It is possible that temporal and harmonic cues do not induce triple meter in infants. Instead, infants may perceive temporal sequences in terms of binary relations. If so, temporal and harmonic accents would align with beats in patterns consistent with duple meter but not in those consistent with triple meter. Thus, infants could be treating sequences in triple meter as nonmetric rhythms. It is clear that infants are better at detecting subtle temporal

deviations in strongly metric rhythms, which feature temporal accents regularly co-occurring with beats, than in weakly metric rhythms, which feature asynchronous accents and beats (Experiment 1). Adults exhibit a duple-meter bias even for melodic sequences that are consistent with triple meter (Dawe et al., 1994; Vos et al., 1994). Nevertheless, adults accurately reproduce rhythms that are consistent with a three-unit clock (triple meter) and a four-unit clock (duple meter) when the temporal accents strongly induce such metric structures. Moreover, their reproductions of rhythms in duple meter (or triple meter) are less accurate when the cues implying triple meter (or duple meter) are made explicit (Essens & Povel, 1985).

Performances of music are rarely mechanical, as were the temporal sequences in the present study. For example, performers shorten or lengthen notated tone durations to achieve their expressive goals (Clarke, 1985; Gabrielsson, 1987, 1993). Adults tend to categorize tones with varying interval durations as long and short, in a 2:1 ratio (Fraisse, 1982; Povel, 1981). In so doing, they ignore subtle deviations in timing, just as infants did in the weakly metric or triple-meter rhythms. In fact, adults have difficulty detecting duration changes when musical tones are lengthened or shortened for expressive purposes (Repp, 1998, 1999). Moreover, such expressive timing often highlights the grouping structure (Repp, 1998). Whether infants would exhibit similar patterns of behavior when listening to expressive performances of music is an important question for future research.

Although the present findings are consistent with processing predispositions for strongly metric rhythms, especially those in duple meter, it is possible that the internal timekeeper becomes fine-tuned by music exposure in the early months of life. Caregivers across cultures sing to their infants (Trehub & Trainor, 1998), and the songs they perform are similar in many respects (Trehub & Schellenberg, 1995; Trehub, Unyk, & Trainor, 1993b). Lullabies across cultures are not necessarily in duple meter, but their simplified rhythms (relative to adult music) and repetitiveness contribute to their perceptual distinctiveness (Trehub et al., 1993a, 1993b). Processing constraints may limit the diversity of temporal structures in music, especially music intended for novice performers or listeners. Groome et al. (2000) reported that fetuses “prefer” pulsed auditory temporal patterns to continuous auditory patterns regardless of their spectral complexity, a finding that is consistent with predispositions for perceiving temporal regularities.

Not all musical forms have metric structure, which calls into question the notion of universal preferences

(i.e., similar preferences regardless of age and culture) for strongly metric rhythms. There are numerous examples of Indian and African music, Gregorian chant, and North American jazz without apparent metric structure, or with structures that are more complex than those of traditional Western music (Blacking, 1973; Hannon & Trehub, 2005a; Lerdahl & Jackendoff, 1983; Magill & Pressing, 1997). Performers may still impose temporal regularity on such music. For example, the Venda of South Africa often clap along with their music, applying a metric structure to seemingly nonmetric or weakly metric rhythms (Blacking, 1973). Magill and Pressing (1997) asked a West African (Asante) master drummer to synchronize with and spontaneously produce a *Kete* temporal pattern. Although a West African timing model provided a better account of his temporal behavior than did a Western model of metric regularity, that was the case only when the drummer played the rhythms in familiar contexts, or those linked to his formal music training. Thus, grouping and metric regularity may be universal building blocks on which more complex rhythmic patterns are superimposed (but see also Locke, 1982).

Infants’ sense of rhythm may be linked to their body movements. Indeed, stereotypical rhythms of head, arm, chest, and leg movements have been observed in infancy (Pouthas, 1996; Thelen, 1981), and early bipedal kicking and sucking have binary elements (e.g., suction and relaxation). Moreover, infants gradually integrate endogenous and exogenous rhythms (Pouthas, 1996). When presented with a “moving room,” for example, infants adjust their rate of swaying to match the frequency of room movements (Bertenthal, Rose, & Bai, 1997). It is notable that caregivers typically move while singing to their infants, which is consistent with the notion of intrinsic connections between rhythm and movement (Cross, 2001; Merker, 2000). Much of the motion that caregivers provide for infants can be considered binary, as in rocking (e.g., back and forth) or bouncing (e.g., up and down). Recent evidence indicates that 7-month-old infants’ interpretation of an ambiguous drum rhythm is affected by the pattern of bouncing (on every second or third beat) that they experienced while listening (Phillips-Silver & Trainor, 2005). Such connections between rhythmic sound and motion go well beyond caregiver-infant interactions, with music being inseparable from movement in many cultures (Fraisse, 1982; Merker, 2000).

Infants are also sensitive to the rhythmic properties of speech. For example, French newborns differentiate English utterances, which are stress-timed, from Japanese utterances, which are timed at the subsyllabic

level, or mora (Nazzi, Bertoncini, & Mehler, 1998). They also differentiate stress-timed English and Dutch utterances from syllable-timed Spanish and Italian utterances, but they show no such differentiation of languages that are stress-timed (Nazzi et al., 1998). If infants attend to rhythmic aspects of speech from the earliest days of life, they are likely to do so with musical patterns. By 5 months of age, they can distinguish the rhythms of their native language from other languages in the same rhythmic family (Nazzi, Jusczyk, & Johnson, 2000). Increasing sensitivity to the rhythmic characteristics of one's native language could affect rhythm perception in music. For example, infants exposed to a syllable-timed language, which has equally stressed syllables, may not attend to the strong and weak beats of musical patterns in the same way as infants exposed to a stress-timed language, which has strong and weak syllables. Indeed, Patel and Daniele (2003) found that rhythmic patterns distinguish French and English classical music as well as spoken language.

Because infants in the present study were exposed to a stress-timed language (English), it is impossible to rule out the influence of linguistic exposure on their perception of musical rhythms. There are indications, however, that culture-specific biases in metrical perception that are characteristic of Western adults are absent in 6- and 7-month-old infants (Hannon & Trehub, 2005a) but present in 12-month-olds (Hannon & Trehub, 2005b).

Predispositions for strongly metric over weakly metric or nonmetric rhythms have been documented in nonhuman species. Although a number of species can discriminate between rhythmic and arrhythmic sequences (e.g., Hulse, Humpal, & Cynx, 1984), the ability to entrain to an external timekeeper or keep a steady beat seems to be uniquely human (Brown, Merker, & Wallin, 2000; Geissmann, 2000; Merker, 2000). According to Molino (2000), rhythm is a critical building block for the syntactic constructions of music and language. Synchronizing to a musical pulse or beat may have its origins in the need to coordinate with others in social groups (Geissmann, 2000; Merker, 2000). Thus, infants' ability to detect changes in strongly metric but not in weakly metric rhythms is consistent with predispositions to synchronize or entrain an internal timekeeper to an external (auditory) temporal sequence.

Such synchronization or entrainment could be guided by expectations induced by strongly metric rhythms, in line with Dynamic Attending Theory

(Drake et al., 2000; Jones & Boltz, 1989). In other words, the regularity of grouping or temporal accents may heighten attention to the tone or beat expected by the listener. For example, adults can find the pulse and synchronize with piano ragtime music when left-hand and right-hand parts are included (Snyder & Krumhansl, 2001). When the predictable bass pattern is removed, leaving the syncopated right-hand melody, listeners produce more off-beat and aperiodic synchronizations and larger deviations from the beat, regardless of the available pitch information. Thus, temporal regularity may create expectancies that allow listeners to follow the beat or pulse of auditory patterns. Such expectancies may account for newborns' reaction to the absence of an expected auditory event or to temporal irregularity (Clifton, 1974; Stamps, 1977).

Drake et al. (2000) contend that such abilities are refined with age and experience, so that older children, adults, and musically trained individuals can entrain to increasingly higher hierarchical levels. Similar age-related changes may occur in other domains of music perception such as melodic implication-realization (Narmour, 1990). When listening to melodic sequences, the structure of one interval (e.g., a large upward pitch interval) leads to expectations about the next interval (e.g., a small downward pitch interval). Children show similar patterns of melodic expectation as adults, but not to the same degree (Schellenberg, Adachi, Purdy, & McKinnon, 2002). Similarly, infants fail to distinguish between patterns that fulfill melodic expectations and those that violate such expectations (Bergeson, 1999). Thus, the formation of melodic and temporal expectations may follow a similar developmental timetable, which is accelerated by experience, enculturation, and formal music training.

Author Note

Tonya R. Bergeson is now at the Department of Otolaryngology-Head & Neck Surgery at Indiana University School of Medicine.

This research was supported by the Natural Sciences and Engineering Research Council of Canada. We thank Marilyn Barras for her assistance in testing infants.

Address correspondence to: Tonya R. Bergeson, Indiana University School of Medicine, Department of Otolaryngology Head & Neck Surgery, 699 West Drive RR044, Indianapolis, IN 46202. E-MAIL tbergeso@iupui.edu

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