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The Development of Music Perception and Cognition

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I. INTRODUCTION

An adult listening attentively to a piece of music and understanding it performs an enormous amount of information processing very rapidly. Most of this processing is carried out automatically below the level of conscious analysis, because there is no time for reflective thought on each detail as the piece steadily progresses. This process is closely parallel to what happens when a native speaker of a language listens to and understands a sentence. The elements of the sentence are processed very rapidly—so rapidly that the listener cannot attend individually to each detail, but simply hears and understands the overall meaning. The rapidity of automatic speech processing depends on extensive perceptual learning with the language in question. Similarly, the music listener's facility in grasping a piece of music depends on perceptual learning gained through experience with the music of a particular culture. Further, we can see in the development of language from its earliest stages the predisposition of the child to speak, and the ways in which basic elements of language, already present in infancy, are molded through perceptual learning and acculturation into adult structures (Brown, 1973). Similarly, we can find elements of adult cognitive structures for music in young infants, and can watch them develop in complexity under the influence of culture and individual experience. In both speech and music, then, there are specific patterns of behavior that emerge in infancy that bear the unmistakable stamp of "speech" or "music" behavior. We can trace the elaboration of those incipient speech and music patterns in the course of development.

A point to be emphasized is the ease and rapidity with which adults perform complex cognitive tasks in domains of speech and music familiar to them, and the degree to which that facility depends on prior experience. For example, when the processing of a melody is complicated by the temporal interleaving of distractor notes among the notes of the melody, listeners are more accurate in judging pitches that match familiar, culturally determined norms than those that do not (Dowling, 1992, 1993a). Furthermore, the ability to discern a target melody in the midst of temporally interleaved distractors grows gradually through childhood, and the importance of the culturally defined tonal scheme to the performance of that task grows as well (Andrews & Dowling, 1991). Perceptual learning with the music of a culture provides the listener with a fund of implicit knowledge of the structural patterns of that music, and this implicit knowledge serves to facilitate the cognitive processing of music conforming to those patterns.

Calling the knowledge amassed through perceptual learning "implicit" indicates that it is not always available to conscious thought. Neither the knowledge base itself nor the cognitive processes through which it is applied are entirely accessible to consciousness (Dowling, 1993a, 1993b). Listeners typically engage in far more elaborate processing than they are aware of. For example, there is evidence that listeners with a moderate amount of musical training encode the diatonic scale-step ("*do, re, mi*") values of the notes of melodies they hear (Dowling, 1986). Yet those listeners are not aware that they are even capable of categorizing melodic pitches according to their scale-step values, much less that they do it routinely when hearing a new melody. Implicit knowledge of Western musical scale structure has accrued over years of experience, and that knowledge is applied automatically and unconsciously whenever the adult listens to music.

This sensorimotor learning undoubtedly has consequences for brain development, as illustrated by Elbert, Pantev, Wienbruch, Rockstroh, and Taub's (1995) demonstration of the enhanced allocation of cortical representation to fingers of the left hand in string players, especially for those who begin study of the instrument before the age of 12. Recent results by Pantev, Oostenveld, Engelien, Ross, Roberts, and Hoke (1998) concerning cortical allocation in processing musical tones tend to confirm this supposition.

In looking at the development of music perception and cognition, one of our goals is to distinguish between cognitive components that are already present at the earliest ages and components that develop in response to experience. We can look at the content of the adult's implicit knowledge base in contrast to the child's. We can also look at the developmental sequence by which the individual goes from the infant's rudimentary grasp of musical structure to the experienced adult's sophisticated knowledge and repertoire of cognitive strategies for applying it.

II. DEVELOPMENT

A. INFANCY

Over the past 20 years, much has been learned about the infant's auditory world. Researchers have isolated several kinds of changes that infants can notice in melodies and rhythmic patterns, and those results give us a picture consistent with the notion that infant auditory perception uses components that will remain important into adulthood. In broad outline it is clear that infants are much like adults in their sensitivity to the pitch and rhythmic grouping of sounds. This is seen in infants' tendency to treat melodies with the same melodic contour (pattern of ups and downs in pitch) as the same and to respond to the similarity of rhythmic patterns even across changes of tempo. Similarly, we find that in children's spontaneous singing, rhythmic grouping and melodic contour are important determinants of structure and that when children begin singing, their singing is readily distinguishable from speech in terms of its patterns of pitch and rhythm. In both perception and production, we find that the child's cognition of musical patterns contains the seeds of the adult's cognition.

1. Prenatal Experience

Even before birth, the infant appears to be sensitive to music, or at least to patterns of auditory stimulation. Research has shown that prenatal auditory stimulation has effects on the infant's behavior after birth. Shetler (1989) has reviewed studies showing that the fetus is responsive to sounds at least as early as the second trimester. Very young infants recognize their mother's voice (DeCasper & Fifer, 1980; Mehler, Bertoncini, Barrière, & Jassik-Gerschenfeld, 1978), and this may derive from neonatal experience with the mother's characteristic patterns of pitch and stress accents. Such an interpretation is plausible in light of the demonstration by DeCasper and Spence (1986) that patterns of a speech passage read repeatedly by their mothers during the third trimester of pregnancy were later preferred by babies. DeCasper and Spence had newborns suck on a blind nipple in order to hear one or another children's story. Children who had been read a story in the womb sucked more to hear that story, while babies who had not been read stories in the womb had no preference between the two stories. Spence and DeCasper (1987) also demonstrated that babies who had been read stories in the womb liked speech that was low-pass filtered (resembling speech heard before birth) as much as normal unfiltered speech, whereas babies who had not been read to did not.

2. Perceptual Grouping

Infants' grouping of sounds in the pitch and time domain appears to follow much the same overall rules of thumb as it does for adults. Just as adults segregate a sequence of notes alternating rapidly between two pitch ranges into two perceptual streams (Bregman & Campbell, 1971; Dowling, 1973; McAdams & Bregman, 1979), so do infants (Demany, 1982). A converging result of Thorpe and Trehub (1989) illustrates this. Thorpe and Trehub played infants repeating six-note sequences such as AAAEEE (where A and E have frequencies of 440 and 660 Hz, a musical fifth apart). They trained the infants to turn their heads to see a toy whenever they heard a change in the stimuli being presented. A background pattern (AAAEEE) would be played over and over. Once in a while a changed pattern would appear. The changes consisted of temporal gaps introduced within perceptual groups (AAAE EE) or between groups (AAA EEE). The infants noticed the changes when they occurred within groups, but not between groups. An additional gap separating patterns that were already perceptually separate was simply lost in processing (as it tends to be by adults).

3. Pitch

Infant pitch perception is quite accurate and also displays some of the sophistication of adult pitch processing. Adults display "octave equivalence" in being able to distinguish easily between a pair of tones an octave apart and a pair of tones not quite an octave apart (Ward, 1954), and so do infants (Demany & Armand, 1984). Adults also have "pitch constancy" in the sense that complex tones with differing harmonic structure (such as different vowel sounds with different frequency spectra) have the same pitch as long as their fundamental frequencies are the same. That is, we can sing "ah" and "ooh" on the same pitch, the listener will hear them that way, and the pitch can be varied independently of vowel timbre by changing our vocal chord vibration rate (and hence the fundamental frequency of the vowel).

Even eliminating the fundamental frequency entirely from a complex tone will not change the pitch as long as several harmonics remain intact (Schouten, Ritsma, & Cardozo, 1962). Clarkson and Clifton (1985) used conditioned head turning to demonstrate that the same is true for infants 7 or 8 months old. Also, Clarkson and Rogers (1995) showed that, just like adults, infants have difficulty discerning the pitch when the harmonics that are present are high in frequency and remote from the frequency of the missing fundamental.

Regarding pitch discrimination, Thorpe (1986, as cited in Trehub, 1987) demonstrated that infants 7–10 months old can discriminate direction of pitch change for intervals as small as 1 semitone. Infants 6–9 months old can also be induced to match the pitches of vowels that are sung to them (Kessen, Levine, & Wendrich, 1979; Révész, 1954; Shuter-Dyson & Gabriel, 1981).

4. Melodic Pitch Patterns

Since early demonstrations by Melson and McCall (1970) and Kinney and Kagan (1976) that infants notice changes in melodies, a substantial body of research by Trehub (1985, 1987, 1990; Trehub & Trainor, 1990) and her colleagues has explored the importance for infants of a variety of dimensions of melodies. Figure 1 illustrates kinds of changes we can make in the pitch pattern of a melody, in this case "Twinkle, Twinkle, Little Star." We can shift the whole melody to a new pitch level, creating a transposition that leaves the pitch pattern in terms of exact intervals from note to note intact (Figure 1b). We can shift the melody in pitch while preserving its contour (pattern of ups and downs) but changing its exact interval pattern (Figures 1c and 1d), creating a same-contour imitation. The altered pitches of the same-contour imitation in Figure 1c remain within a diatonic major scale, while those in Figure 1d depart from it. Finally, we can change the contour (Figure 1e), producing a completely different melody. Changes of contour are easily noticed by adults, whereas patterns with diatonic changes of intervals (Figure 1c) are

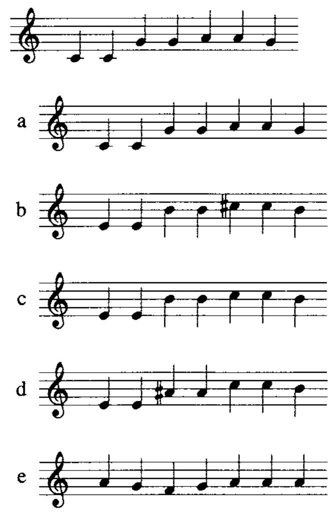

FIGURE 1 Examples of types of stimuli described in the text. At the top is the first phrase of the familiar melody, "Twinkle, Twinkle, Little Star," with the intervals between successive notes in semitones of [0, +7, 0, +2, 0, –2]. Following it are (a) an exact repetition [0, +7, 0, +2, 0, –2]; (b) a transposition to another key [0, +7, 0, +2, 0, –2]; (c) a tonal imitation in the key of the original [0, +7, 0, +1, 0, –1]; (d) an imitation not in any major key [0, +6, 0, +2, 0, –1]; and (e) a melody with a different contour ("Mary Had a Little Lamb") [–2, –2, +2, +2, 0, 0].

often hard to discriminate from transpositions (Figure 1b; Dowling, 1978; Dowling & Fujitani, 1971).

Chang and Trehub (1977a) used heart-rate deceleration to indicate when a 5-month-old notices something new. Babies adapted to a continuously repeating six-note melody. Then Chang and Trehub substituted an altered melody to see if the baby would notice. When the stimulus was simply transposed 3 semitones (leaving it in much the same pitch range as before) the babies did not notice, but when the melody was shifted 3 semitones in pitch and its contour was altered, the babies showed a heart-rate deceleration "startle" response. For infants as for adults, the transposition sounds like the same old melody again, whereas the different-contour melody sounds new.

This result was refined in a study of 8- to 10-month-olds by Trehub, Bull, and Thorpe (1984). As in Thorpe and Trehub's (1989) study just described, Trehub et al. used conditioned head turning as an index of the infant's noticing changes in the melody. A background melody was played over and over. When a comparison melody replaced the background melody on a trial, the infants were able to notice all the changes Trehub et al. used: transpositions, same-contour-different-interval imitations, different-contour patterns, and patterns in which individual notes were displaced by an octave in a way that either violated, or did not violate, the contour. In this last transformation, the changes preserved *pitch class* by substituting a note an octave away that changed the contour. Pitch class depends on octave equivalence; all the members of a pitch class lie at octave multiples from each other. Contour changes were most noticeable. In a second experiment, Trehub et al. used the same task but made it more difficult by interposing three extra tones before the presentation of the comparison melody. In that case, infants did not notice the shift to transpositions and contour-preserving imitations, but they did notice changes in contour. This result was replicated with stimuli having even subtler contour changes by Trehub, Thorpe, and Morrongiello (1985).

The foregoing studies show that infants, like adults, easily notice differences in melodic contour. But, as Trehub, Thorpe, and Morrongiello (1987) point out, the studies do not demonstrate that infants in fact treat contour as a feature of melodies to be remembered. To show that, we would need to show that infants were abstracting a common property, an invariant, from a family of similar melodies that share only contour, and contrasting that property with that of melodies from another family with a different contour. To accomplish this, Trehub et al. (1987) used the conditioned-head-turning paradigm but with a series of background patterns that varied. In one condition, the background melodies varied in key and were all transpositions of one another. In a second condition, the background melodies were all contour-preserving imitations of one another, but not exact transpositions. In fact, infants were able to notice changes among the background melodies, which were changes involving pitches (in the transposition set) and both intervals and pitches (in the imitation set). But they noticed changes of contour even more, supporting the notion that infants, like adults, encode and remember the contours of melodies they hear.

The results reviewed so far suggest considerable qualitative similarity between infants and adults in their memory for melodies. Both are able to notice changes in intervals and pitch levels of melodies under favorable conditions, but both find changes of melodic contour much more salient. The principal differences between infants and adults in the processing of pitch information in melodies arise from the acculturation of the adults in the tonal scale system of a particular culture. Virtually every culture in the world has at least one systematic pattern for the organization of pitch classes that repeats from octave to octave (Dowling & Harwood, 1986). The most common pattern in Western European music is that of the major ("*do, re, mi*") scale. Melodies that conform to that pattern are easier for Western European adults to encode and remember than melodies that do not (Cuddy, Cohen, & Mewhort, 1981; Dowling, 1991). However, as can be inferred from their cross-cultural variation, such scale patterns are not innate. There is no reason a priori for infants to find one pitch pattern easier than another.

This last point will probably strike psychologists as noncontroversial, but there is a very strong tradition among theorists of Western music going back to Pythagoras that attributes the structure of the Western scale system not only to innate cognitive tendencies, but, even further, to the structure of the universe itself in terms of simple whole-number ratios (Bernstein, 1976; Helmholtz, 1877/1954; Hindemith, 1961). The most sensible answer to these questions appears to be that there are certain constraints of human cognition that apply to musical scale structures but that within those constraints a very wide range of cultural variation occurs (Dowling & Harwood, 1986). The main constraints are octave equivalence (involving a 2/1 frequency ratio), a weaker tendency to give importance to the perfect fifth (a 3/2 ratio), coupled with a limit of seven or so pitch classes within the octave, in agreement with George Miller's (1956) argument concerning the number of categories along a perceptual dimension that humans can handle.

In a study bearing on the inherent importance of the perfect fifth, Trehub, Cohen, Thorpe, and Morrongiello (1986) used conditioned head turning to assess the performance of 9- to 11-month-olds in detecting changes of single pitches in a simple diatonic melody (C-E-G-E-C) and in a corresponding nondiatonic melody with an augmented fifth (C-E-G♯-E-C). They found no difference between the two background melodies, suggesting the lack of a strong inherent preference for the size of the fifth. Children between 4 and 6 years of age, however, did show a difference favoring the diatonic melody. Thus acculturation in the tonal scale system is already well begun by that age.

There is some evidence, however, in favor of the primacy of the perfect fifth. Cohen, Thorpe, and Trehub (1987) complicated the task used by Trehub et al. (1986) by transposing the background melody to a new pitch level with each repetition. In that case, the task could not be solved simply by noticing changes of single pitches, but would require the abstraction of the invariant interval pattern of the background melody. Under those conditions, 7- to 11-month-olds found changes easier to detect in the diatonic pattern (C-E-G-E-C) than in the nondiatonic pattern (C-E-G♯-E-C). Seven to 11 months is a rather wide age range in the life of a rapidly changing infant. Lynch and Eilers (1992) differentiated the ends of that range by running 6-month-olds and 12-month-olds in parallel tasks. They found that although the 12-month-olds performed like the 7- to 11-month-olds in the Cohen et al. (1987) study, the 6-month-olds performed equally well with the diatonic and nondiatonic patterns. That is, the younger infants were not yet acculturated to the standard Western diatonic scale as distinct from other arrangements of semitone intervals, whereas the older infants were.

In addition to the diatonic and nondiatonic patterns using Western "tonal material" (Dowling, 1978) consisting of intervals constructed of semitones, Lynch and Eilers (1992) also included a non-Western pattern: a Javanese *pélog* scale pattern that did not contain a perfect fifth and in which some of the pitches approximated quarter steps lying in between the semitones on the piano. The performance of the 6-month-olds, which was better than chance (and equally good) for diatonic and nondiatonic Western patterns, decreased to chance levels for the Javanese pattern (as did the performance of the12-month-olds). Thus the 6-month-olds were either acculturated at the level of Western tonal material, or there is something about scale structures constructed with a logarithmic modulus such as the semitone (shared by the diatonic and nondiatonic patterns) that makes patterns constructed in them naturally easier to process. I favor the former explanation in terms of acculturation, because if conformity to "natural" pitch intervals were important, the most obvious candidate for a natural interval conducive to "good" pattern construction (in the Gestalt sense) is the perfect fifth (C-G, the 3/2 ratio) contained in the diatonic but not the other two patterns. This possibility is suggested by Trainor (1993), Trehub, Thorpe, and Trainor (1990), and Schellenberg and Trehub (1994) in their discussions of the diatonic/nondiatonic distinction made by the older infants. The perfect fifth is a fundamental building block in the traditional scale systems of India, China, and the American Indians, as well as of Europe (Dowling & Harwood, 1986), and is represented in the harmonic structure of complex tones such as vowel sounds, and also is prevalent in music (as at the start of "Twinkle, Twinkle," Figure 1). Thus if the perfect fifth, as a natural interval, were an important determinant of infant responses to scale patterns, the 6-month-olds would have performed better with the diatonic patterns than with the other two patterns. They did not, so it seems unlikely to me that the semitone, rarely explicitly present in the patterns and a far more remote candidate for natural interval, would play such a role.

If the younger infants are acculturated in terms of semitones, it remains nevertheless true that they are not sensitive to subtler aspects of the diatonic scheme. This is seen in their indifference both to the diatonic/nondiatonic distinction and to diatonic key membership of target tones, as shown by Trainor and Trehub (1992). Trainor and Trehub tested 8-month-olds using a strongly diatonic background melody. Comparison melodies had an altered pitch that either remained within the key of the background melody or went outside it. Infants detected the change equally well whether it remained within the key or not. Their performance was unaffected by tonal scale structure. Adults, in contrast, found out-of-key alterations much easier to detect. (In fact, out-of-key alterations sound quite startling to adults unless they are "anchored" to a new key as the result of modulation—Bartlett, 1993; Bartlett & Dowling, 1988; Bharucha, 1984, 1996.) In fact, infants' performance with within-key alterations was superior to that of adults! Adults found the within-key alterations difficult to detect because the tonal framework they had acquired through lifelong perceptual learning made the within-key notes sound like natural continuations of the melody, even though they were the wrong notes. (Trainor & Trehub, 1993, extended these results to show that infants were more sensitive to changes in both patterns when they were transposed to a closely related key vs. a distant key—see the discussion of key-distance effects later.)

In summary, we can say that infants, like adults, find melodic contour a very salient feature of melodies. However, the process of acculturation in pitch-scale patterns is a long, slow process. By 6 months the infant is beginning that process at the level of the tonal material. By 1 year the infant responds differently to diatonic and nondiatonic patterns. But, as described below, listeners require more years of acculturation before they hear pitches automatically in terms of a tonal frame of reference.

5. Rhythm

As noted in the earlier discussion of perceptual grouping, infants' temporal grouping of tone sequences is much like that of adults. Infants have been shown to discriminate between different rhythmic patterns (Chang & Trehub, 1977b; Demany, McKenzie, & Vurpillot, 1977). However, those tasks could have been solved on the basis of absolute rather than relative temporal relationships. Just as a melody retains its identity across transposition, so that relative and not absolute pitches are important, so a rhythmic pattern retains its identity across changes in tempo, where relative rather than absolute timing of the notes is important (Monahan & Carterette, 1985). And just as infants are sensitive to changes in patterns of relative pitch, they are sensitive to changes in the relative temporal patterns of rhythms. Trehub and Thorpe (1989), again using conditioned head turning, showed that infants 7–9 months old could notice changes in rhythmic patterns (such as XX XX vs. XXX X) even across variations in tempo. Just as for adults, a rhythmic pattern retained its identity when presented faster or slower.

Infants' broader rhythmic organization of musical phrases is like adults' in a surprising way. Krumhansl and Jusczyk (1990) presented 4- and 5-month-olds with Mozart minuets that had pauses inserted between phrases or within phrases. The infants preferred to listen to versions with pauses between phrases, suggesting that the infants were sensitive to cues to adult phrase structure of musical pieces. It remains to be seen exactly what cues the infants were responding to. Jusczyk and Krumhansl (1993) extended those results to show that the infants were really responding to phrase structure (and not just Mozart's beginning and ending patterns in the minuets) and that the pitch contour and note duration are important determinants of the infants' response to structural pauses. Furthermore, infants tended not to notice pauses inserted at phrase boundaries in naturally segmented minuets.

B. CHILDHOOD

During their second year, children begin to recognize certain melodies as stable entities in their environment and can identify them even after a considerable delay. My older daughter at 18 months would run to the TV set when she heard the "Sesame Street" theme come on, but not for other tunes. At 20 months, after a week or so of going around the house singing "uh-oh" rather loudly to a descending minor third, she responded with the spoken label "uh-oh" when I played that pattern on the piano.

1. Singing

Children begin to sing spontaneously somewhere around the age of 9 months or a year. At first this can take the form of vocal play that includes wild excursions over the child's entire pitch range, but it also includes patterns of vowel sounds sung on locally stable pitches. This last is a feature that distinguishes singing from the child's incipient speech at this age.

Especially after 18 months, the child begins to generate recognizable, repeatable songs (Ostwald, 1973). The songs of a child around the age of 2 years often consist of brief phrases repeated over and over. Their contours are replicable, but the pitch wanders. The same melodic and rhythmic contour is repeated at different pitch levels, usually with different intervals between the notes. The rhythm of these phrases is coherent, with rhythms often those of speech patterns. Accents within phrases and the timing of the phrases themselves is determined by a regular beat pattern. This two-level organization of beat and within-phrase rhythm is another feature that distinguishes singing from speech and is characteristic of adult musical organization (Dowling, 1988; Dowling & Harwood, 1986).

An example of a spontaneous song from my daughter at 24 months consisted of an ascending and descending phrase with the words "Come a duck on my house" repeated 10 or 12 times at different pitch levels with small pitch intervals within phrases. This song recurred for 2 weeks and then disappeared. Such spontaneous songs have a systematic form and display two essential features of adult singing: they use discrete pitch levels, and they use the repetition of rhythmic and melodic contours as a formal device. They are unlike adult songs, however, because they lack a stable pitch framework (a scale) and use a very limited set of phrase contours in one song—usually just one or two (Dowling, 1984). A more sophisticated construction by the same child at 32 months can be seen in Figure 2. The pitch still wanders but is locally stable within phrases. Here three identifiable phrases are built into a coherent song.

The preceding observations are in general agreement with those of Davidson, McKernon, and Gardner (1981; Davidson, 1985; McKernon, 1979) on spontaneous singing by 2-year-olds. Davidson et al. extended naturalistic observation by teaching a simple song to children across the preschool age range. Two- and 3-year-olds generally succeeded in reproducing the contours of isolated phrases. Older children were able to concatenate more phrases in closer approximations to the model. It was only very gradually across age that the interval relationships of the major scale began to stabilize. Four-year-olds could stick to a stable scale pattern within a phrase but would often slip to a new key for the next phrase, just as the 3-year-old in Figure 2. It was not until after age 5 that the children could hold onto a stable tonality throughout the song. Further, with a little practice, 5-year-olds were able to produce easily recognizable versions of the model. My own observations suggest that the typical 5-year-old has a fairly large repertoire of nursery songs of his or her culture. This emerges when children are asked to sing

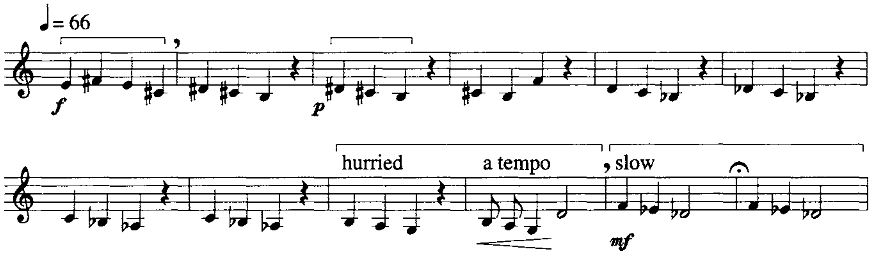

FIGURE 2 A child's spontaneous song at 32 months. Each note was vocalized to the syllable "Yeah." Brackets indicate regions of relatively accurate intonation. Elsewhere intonation wandered.

a song and can respond with a great variety of instances. It is also apparent from their better performance on memory tasks using familiar materials (vs. novel melodies; Andrews & Dowling, 1991). Through the preschool years, the use of more or less stable tonalities for songs comes to be established.

2. Absolute Pitch

Absolute pitch is the ability to identify pitches by their note names even in the absence of musical context. Absolute pitch is not an essential ability for the understanding of most music, although it can aid in the tracking of key relationships in extended passages of tonal music (as in Mozart and Wagner) and in singing 12-tone music on sight. There are times when it can be a hindrance to music cognition by discouraging some of its possessors from developing sophisticated strategies for identifying pitch relationships in tonal contexts (Miyazaki, 1993). Absolute pitch has typically been quite rare even among musicians, occurring in only about 4–8%. However, in cultures where early music training is encouraged, such as in present-day Japan, the incidence of absolute pitch among the musically trained is much higher, possibly near 50% (Miyazaki, 1988). Ogawa and Miyazaki (1994) suggest on the basis of studies of 4- to 10-year-old children in a keyboard training program that most children have the underlying ability to acquire absolute pitch. In their review of the literature, Takeuchi and Hulse (1993) argue in favor of an "early-learning" hypothesis—that absolute pitch can be acquired by anyone, but only during a critical period ending in the fifth or sixth year.

Although relatively few adults can identify pitches, adults typically are able to approximate the pitch levels of familiar songs, a capacity that Takeuchi and Hulse (1993) call "residual absolute pitch." For example, Halpern (1989) found that adults would typically begin the same song on close to the same pitch after an extended delay. Levitin (1994), using the album cover as a retrieval cue, found that young adults sang popular songs they had heard only in one recorded version at approximately the correct pitch level. (Two thirds of the subjects were within 2 semitones of the correct pitch.)

The studies on pitch encoding cited earlier (Dowling, 1986, 1992) suggest that with a moderate amount of training people develop a "temporary and local" sense of absolute pitch that leads them to encode what they hear (and produce) in terms of the tonal framework provided by the current context.

3. Melodic Contour and Tonality

In perception and in singing, melodic contour remains an important basis for melodic organization throughout childhood. Morrongiello, Trehub, Thorpe, and Capodilupo (1985) found 4- to 6-year-olds very capable in discriminating melodies on the basis of contour. Pick, Palmer, Hennessy, Unze, Jones, and Richardson (1988) replicated that result and found that 4- to 6-year-olds could also use contour to recognize same-contour imitations of familiar melodies. In another task emphasizing the recognition of similarity among same-contour imitations of familiar tunes, Andrews and Dowling (1991) found 5- and 6-year-olds performed equally well at recognizing familiar versions and both tonal and atonal imitations. It was not until ages 7 and 8 that tonality began to be a factor in that experiment and only by ages 9 or 10 that a difference appeared between familiar versions and same-contour imitations (the adult pattern of performance).

Studies of perception and memory provide converging evidence with that from singing concerning the 5- or 6-year-old's acquisition of a stable scale structure. With highly familiar tunes such as "Happy Birthday" and "Twinkle, Twinkle," even 4-year-olds can notice "funny" sounding versions with out-of-key pitches (Trehub, Morrongiello, & Thorpe, 1985). And Bartlett and Dowling (1980, Experiment 4) found that 5-year-olds can use musical key differences to discriminate between melodies. On each trial of the experiment, a familiar melody was presented, followed by either a transposition or a same-contour imitation. The comparison was either in the same key as the standard or a nearly related key, or it was in a distant key. (Near keys share many overlapping pitches in their scales; distant keys share few.) Adults in this task are highly accurate in saying "Same" to transpositions (>90%) and not saying "Same" to imitations (<10%). The pattern for 5-year-olds was very different: they tend to say "Same" to near-key comparisons (both transpositions and imitations) and "different" to far-key comparisons. Five-year-olds have one component of the adult behavior pattern—the ability to distinguish near from far keys—but not the other component—the ability to detect changes of interval sizes in the tonal imitations. They accept same-contour imitations as versions of the tune. As the child grows older, the pattern of response moves in the adult direction, so that an 8-year-old accepts near-key imitations less often than far-key transpositions. Eight-year-olds can use both key distance and interval changes to reject a same-contour imitation, whereas 5-year-olds rely principally on key distance.

The 5- to 6-year-old's grasp of stable tonal centers fits other results in the literature. For example, in a series of studies Riley and McKee (1963; Riley, McKee, Bell & Schwartz, 1967; Riley, McKee & Hadley, 1964) found that first graders have an overwhelming tendency to respond by choosing a pitch match rather than an interval match. This tendency to respond to the pitch tasks in terms of a stable frame of reference contrasted with the same children's ability to respond to loudness-comparison tasks in terms of relative (not absolute) loudness.

The emergence of tonal scale relationships among the child's cognitive structures has implications for the conduct of research. Using atonal materials with infants has little impact on the results, because babies do not respond to tonal scale structures as such (Trainor & Trehub, 1992). But Wohlwill's (1971) use of atonal (and to the adult ear rather strange sounding) melodies probably led to his result that first graders could distinguish targets from different-contour lures at a level barely better than chance. At any rate, Wohlwill's conclusion that "the establishment of pitch as a directional dimension is a relatively late phenomenon" could not be true in the light of Thorpe's result with infants (1986, cited in Trehub, 1987). What is true is that first graders have trouble using words to describe pitch direction (Hair, 1977; Zimmerman & Sechrest, 1970).

During later childhood, the child continues to develop sophistication in the use of the tonal scale framework determined by the culture. This progress is illustrated by Zenatti (1969), who studied memory for sequences of three, four, and six notes with subjects from age 5 years up. On each trial, a standard melody was followed by a comparison melody in which one note of the standard had been changed by 1 or 2 semitones. The subject had to say which of the notes had been changed—a very difficult task. Zenatti found that for the three-note sequences, 5-year-olds performed at about chance with both tonal and atonal stimuli. From ages 6 through 10, the results for tonal and atonal sequences diverged, with better performance on tonal sequences. Then, at around age 12, processing of the atonal sequences caught up. For four- and six-note sequences, the same pattern appeared, but the tonal-atonal difference remained until adulthood. Experience with the tonal scale system leads people to improve on recognition of tonal melodies but not atonal melodies. With simple stimuli such as the three-note melodies, atonal performance catches up relatively soon, but longer sequences continue to benefit from the tonal framework throughout childhood. (This result converges with that of Morrongiello & Roes, 1990.) Superiority of recognition with tonal materials has been often observed with adults (Dowling, 1978; Francès, 1958/1988); Zenatti's study shows that the effect can be used as an index of the child's acquisition of the scale structures of the culture.

Trainor and Trehub (1994) took the development of the role of tonality in the ability to detect melodic pitch changes one step further. In addition to alterations that either remained within key or departed from the key, Trainor and Trehub introduced changes that remained in the key but departed from the particular harmony implied by the melody. For example, the first four notes of "Twinkle, Twinkle" (Figure 1a: C-C-G-G) imply harmonization with the tonic triad (C-E-G). A change of the third note from G to E would remain within both the key and the implied harmony. A change to F would remain within the key, but violate the harmony. Trainor and Trehub found that 7-year-olds, like adults, could detect the out-of-key and out-of-harmony changes much more easily than the within-harmony changes, whereas 5-year-olds reliably detected only the out-of-key changes. As Trainor and Trehub (1994, p. 131) conclude, "5-year-olds have implicit knowledge of key membership but not of implied harmony, whereas 7-year-olds, like adults, have implicit knowledge of both aspects of musical structure." In a result that converges with these studies, Imberty (1969, chapter 4) found that 7-year-olds could tell when a melody had been switched in midstream from one key to another or from the major mode to the minor.

Krumhansl and Keil (1982) provide a good picture of the child's progress in grasping the tonal framework. They had children judge the goodness of melodic patterns beginning with an outline of the tonic triad (C-E-G) and ending on an arbitrarily chosen pitch. Krumhansl (1990) had found that adults in that task, especially musically experienced adults, produce a profile in which important notes in the tonal hierarchy (such as those of the tonic triad) receive high ratings and less important notes receive progressively lower ratings in accordance with their importance in the key. Krumhansl and Keil found that 6- and 7-year-olds distinguished simply between within-key notes and outside-of-key notes. The structure of the tonal hierarchy became more differentiated with age, so that by the age of 8 or 9 children were distinguishing between the pitches of the tonic triad and the other pitches within the key.

Two similar studies illustrate the importance of seemingly minor methodological details in research on the development of the tonal hierarchy. Cuddy and Badertscher (1987) simplified the task by using patterns with five notes instead of six. In that case, even 6- and 7-year-olds displayed the principal features of the adult hierarchy. And Speer and Meeks (1985) used an unstable context of the first seven notes of a C-major scale, ending on B or D (in contrast to the stable triad context in Krumhansl & Keil, 1982), to find that 8- and 11-year-olds perform very much like adults.

Lamont and Cross (1994) criticize the use of triads and scales as contexts in the foregoing three studies on two grounds. First, they suggest that these prototypical contexts, always the same throughout a condition of the experiment, are not very representative of the varied character of real tonal music. Second, they note that if children are exposed to any music class activities, the children will probably already have encountered scales and arpeggios. As Lamont and Cross (1994, p. 31) say, "Presented with an overlearned pattern, ... the listener [could be expected] to give an overlearned response appropriate to that pattern." To produce more representative contexts, Lamont and Cross borrowed a method from West and Fryer (1990) of using a different random permutation of the notes of the major scale on each trial, and they also used chord progressions establishing the key. The study included five groups of children between 6 and 11 years old. Like Speer and Meeks (1985) and Cuddy and Badertscher (1987), Lamont and Cross found the children relatively sophisticated in their differentiation of the tonal hierarchy, but they also found, in agreement with Krumhansl and Keil (1982), that the children's representations of musical pitch gained in sophistication through the elementary school years. Lamont and Cross supplemented this study with converging evidence from a series of more open-ended tasks, such as arranging chime bars in order according to pitch and arranging them to create a tune.

In summary, the development of melody-processing skills can be seen as a progression from the use of gross, obvious features to the use of more and more subtle features. Babies can distinguish pitch contours and produce single pitches. Around the age of 5, the child can organize songs around stable tonal centers (keys) but does not yet have a stable tonal scale system that can be used to transpose melodies accurately to new keys. The scale system develops during the elementary school years and confers on tonal materials an advantage in memory that remains into adulthood.

4. Rhythm

There are two aspects of musical rhythm that I wish to discuss in terms of development in childhood. First is the development of the ability to control attention in relation to the temporal sequence of events, using regularities in the rhythm of occurrence of critical features in a piece to aim attention at important elements. Second is the development of the ability to remember and reproduce rhythmic patterns.

Adults in listening to speech and music are able to use their experience with similar patterns to focus their attention on critical moments in the ongoing stream of stimuli to pick up important information (Jones, 1981). This ability requires perceptual learning to develop. Andrews and Dowling (1991) studied the course of this development using a "hidden melodies" task in which the notes of a target melody such as "Twinkle, Twinkle" are temporally interleaved with random distractor notes in the same pitch range, the whole pattern being presented at 6 or 8 notes/sec. After about an hour of practice, adults can discern the hidden melody when they are told which target melody to listen for (Dowling, 1973; Dowling, Lung, & Herrbold, 1987). Andrews and Dowling (1991) included an easier condition in which the interleaved distractor notes were presented in a separate pitch range from the notes of the target. They reasoned that as listeners learned to aim attention in pitch, the listeners would find it easier to discern the targets in a separate pitch range. Five- and 6-year-olds perform barely better than chance on this task and find targets equally difficult to discern whether in a separate range from the distractors or not. It is not until the age of 9 or 10 that the separation of pitch ranges confers an advantage, suggesting that by that age listeners are able to aim their attention at a particular pitch range. Ability to aim attention in time improves steadily from age 6 on, and by age 9, discerning hidden targets with distractors in the same pitch range has reached 70% (with chance at 50%). Musically untrained adults achieve about 80% on this task, while musically experienced adults find the hidden targets equally easy to discern (about 90%) with distractors inside as well as outside the target pitch range.

There is evidence for the importance of a hierarchical organization of rhythm in 5-year-olds' reproductions of rhythmic patterns. Drake (1993) found 5-year-olds able to reproduce rhythms with two levels of organization: a steady beat and varying binary subdivisions of the beat. Although children that age find it easy to tap isochronous (steady, nonvarying) sequences in either binary or ternary rhythm, they find binary sequences with varying patterns within the beat easier than ternary. Drake reports that by the age of 7, children improve in reproducing models that include a variety of different durations in the same sequence, having gained facility with greater rhythmic complexity.

Accents in music can occur on various levels of structure. In particular, accents can be produced in terms of the two levels of beat and rhythmic organization. The beat or meter provides accents at regular time intervals. Rhythmic accents are generally conferred on the first and last members of rhythmic groups. A third level of accents can arise from discontinuities in the melodic contour, such as leaps and reversals of direction. Drake, Dowling, and Palmer (1991) constructed songs in which accents on those levels either coincided or did not. Desynchronization of accent structure lowered children's performance in singing the songs, but there was little change in singing accuracy for children who are between 5 and 11 years old.

These results suggest that by the age of 5 children are responding to more than one level of rhythmic organization and that the songs they learn are processed as integrated wholes in the sense that events at one level affect performance at another; for example, complication of accent structure produces decrements in pitch accuracy in singing. An additional example is provided by Gérard and Auxiette (1988), who obtained rhythm reproductions from 5-year-olds. Gérard and Auxiette either provided the children with a plain rhythmic model to reproduce or provided additional context for the rhythm by providing either words to be chanted to it, or a melody to be sung to it, or both. They found that children with musical training performed best in tapping the rhythm when there was a melody, and children without musical training performed best when there were words. Having words or melody aided in the processing of the rhythm. Gérard and Auxiette (1992) also found that 6-year-old musicians were better able than nonmusicians to synchronize their tapping and their verbalizations in such a task.

The picture that emerges of the development of rhythmic organization is that a multilevel structure appears early and that by the age of 5, the child is quite sophisticated. There is some development in the school-age years, but Drake (1993), for example, found little difference between 7-year-olds and adult nonmusicians. Already the spontaneous songs of a 2-year-old show two levels of rhythmic organization, the beat and rhythmic subdivisions (often speech rhythms) overlaid on that, and the 5-year-old follows the same hierarchical organization in tapped reproductions. Finally, rhythmic organization is not easily separable from other aspects of structural organization in a song, so that in perception and production other aspects of melody are intertwined with rhythmic structure.

5. Emotion

Ample evidence has accumulated that children during the preschool years learn to identify the emotional states represented in music, and this ability improves during the school years. For example, both Cunningham and Sterling (1988) and Dolgin and Adelson (1990) showed that by the age of 4, children perform well above chance in assigning one of four affective labels (essentially "happy," "sad," "angry," and "afraid") to musical excerpts in agreement with adults' choices. (With the exception of Cunningham and Sterling, all the studies reviewed here had subjects choose schematic faces expressing the emotions in making their responses.) Both of these studies also showed that performance improves over the school years. Performance was less than perfect at the earlier ages, and in particular, Cunningham and Sterling found that 4-year-olds were not consistently above chance with "sad" and "angry," nor 5-year-olds with "afraid," whereas Dolgin and Adelson found 4-year-olds at about chance with "afraid." In a similar study, Terwogt and Van Grinsven (1991) found that 5-year-olds performed very much like adults, but that all ages tended to confuse "afraid" and "angry." These studies were able in a general way to attribute the children's responses to features of the music, but there are other studies that have focused on specific musical features such as the contrast between major and minor.

The issue of whether the major mode in Western music is a cue to happy emotions, and the minor mode a cue to sad ones, has been a perennial issue for both musicologists and psychologists. A particular developmental issue arises here, because we can ask whether responses to the affective connotations of major and minor appear earlier than the specific cognitive recognition of the difference, which, according to the foregoing review, appears around the age of 5. In exploring these issues, Gerardi and Gerken (1995) restricted responses to the choice of two faces, "happy" or "sad," and used adaptations of musical passages that differed in mode (major vs. minor) and predominant melodic contour (up vs. down). They found that 8-year-olds and adults, but not 5-year-olds, applied "happy" and "sad" consistently to excerpts in the major and minor, respectively. Only adults consistently chose "happy" for ascending contours and "sad" for descending, although that variable was probably not manipulated very strongly. (For example, "Che faro" from Gluck's *Orfeo ed Euridice* fails to ascend or descend unambiguously.)

In contrast to Gerardi and Gerken, Kastner and Crowder (1990) allowed subjects a choice of four faces—"happy," "neutral," "sad," and "angry"—and used versions of three different tunes presented in the major and minor, and with or without accompaniment. They found that when relatively positive responses (happy or neutral) were contrasted with negative responses (sad or angry), even 3-year-olds consistently assigned positive faces to major and negative faces to minor. This tendency became stronger between 3 and 12 years of age. Therefore, we can say that there is some indication that preschoolers are able to grasp the emotional connotations of the two modes at an earlier age than they can differentiate their responses in a more cognitively oriented task.

C. ADULTHOOD

Rather than include here a comprehensive review of adults' implicit knowledge of musical structure, I shall concentrate on some issues concerned with tonality and the tonal scale framework. Adults in Western European cultures vary greatly in musical ability. Sometimes these individual differences are reflected in performance on perception and memory tasks. Untrained subjects usually do not find contour recognition more difficult than trained subjects (Dowling, 1978) but do find interval recognition (Bartlett & Dowling, 1980; Cuddy & Cohen, 1976) and the hearing out of partials in a complex tone (Fine & Moore, 1993) more difficult. Even where nonmusicians perform worse overall on tasks involving memory for melodies, they are often just as influenced as musicians by variables such as tonality, performing worse with atonal than with tonal melodies (Dowling, 1991). Also, nonmusicians are just as error prone as musicians when dealing with nonstandard quarter steps that fall in cracks in the musical scale (Dowling, 1992). Such qualitative results show that nonmusicians have acquired at least a basic tonal scale framework from their experience in the culture and that that framework has a psychological reality independent of its use as a pedagogical tool.

During the past few years, evidence has been accumulating that listeners routinely encode the music they hear in absolute, and not relative, terms. For example, when presented with novel melodies and then tested after filled delays of up to 1.5 min, listeners find it easier to discriminate between targets (like Figure 1b, only novel) and same-contour lures (like Figure 1c), than between targets and different-contour lures (like Figure 1e; Dowling, Kwak, & Andrews, 1995). (With familiar melodies such as those shown in Figure 1, those abilities are about equal after 2 min.) That is, after a delay, listeners find it easier to discriminate very fine differences between the test melody and the melody they heard than to discriminate gross differences (DeWitt & Crowder, 1986; Dowling & Bartlett, 1981). Their memory represents very precisely what they have heard. This evidence converges with the demonstration by Levitin (1994), reviewed earlier, that nonmusicians come very close to the correct absolute pitch when singing familiar popular songs and with the similar demonstration by Levitin and Cook (1996) that their approximations of the tempos of such songs are quite accurate. This makes it seem likely that memory for music typically operates in terms of more precise representations of particular stimuli than has been generally thought (e.g., by Dowling, 1978).

Among adults, striking differences in performance based on different levels of musical experience sometimes appear, illustrating different ways in which knowledge of scale structure can be used. Dowling (1986) demonstrated differences among three levels of sophistication in a study of memory for novel seven-note melodies. Dowling presented the melodies in a context of chords that defined each melody as built around the tonic (the first degree of the scale, *do*) or the dominant (the fifth degree, *sol*). Listeners had to say whether notes had been altered when the melody was presented again. The test melodies were also presented with a chordal context, and that context was either the same as before or different. The test melodies were either exact transpositions or altered same-contour imitations of the original melodies. Musically untrained listeners performed equally well with same or different chord context at test. Listeners with moderate amounts of training in music (around 5 years of lessons when they were young) performed much worse with changed context. That suggests that those listeners were initially encoding the melodies in terms of the tonal scale values provided by the context, so that when the context was shifted, the melody was very difficult to retrieve. In contrast, nonmusicians simply remembered the melody independent of its relation to the context. Professional musicians performed very well with both changed and unchanged contexts. Their sophistication gave them the flexibility to ignore the context where it was not useful.

III. SUMMARY

Adults bring a large store of implicit knowledge to bear in listening to music. This knowledge includes implicit representations of the tonal framework of the culture in terms of which expected events are processed efficiently and in terms of which pitches are interpreted in their musical context. This store of knowledge includes knowledge of the timing patterns of music in the culture, so that the listener is able to focus attention on moments in time at which critical information is likely to occur. Although musical experience leads, as we have seen, to greater sophistication in the store of implicit knowledge, nevertheless nonmusicians have typically acquired the fundamentals of this knowledge from their experience listening to music throughout their lives. Thus nonmusicians are sensitive to shifts in tonality and to the multilevel structure of rhythmic organization.

The implicit knowledge of adults is built on elements present even in infancy: the importance of melodic and rhythmic contours, the use of discrete, steady pitch levels, the organization of rhythmic patterns into a steady beat and an overlay of more complicated rhythms, and octave equivalence, to name a few. These elements provide the groundwork for perceptual learning and acculturation throughout life to build upon.

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