MUSICAL ENCULTURATION IN CHILDREN

ENCULTURATION TO WESTERN MUSICAL PITCH STRUCTURE IN YOUNG CHILDREN

By

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Abstract

I examined the development of sensitivity to two fundamental aspects of Western musical pitch structure, key membership and harmony, which can be acquired without formal training. In Chapter 2 (Experiment 1), I describe the novel and engaging behavioural task that I designed in order to study a younger age group than in previous research. On each trial, children watched videos of puppets playing unfamiliar piano melodies and chord sequences, in which one puppet's music conformed to Western pitch structure and the other's did not. Children judged which of the two puppets played the best song. Five-year-olds demonstrated sensitivity to key membership but not harmony, whereas 4-year-olds demonstrated sensitivity to neither. However, event-related potential (ERP) responses to a subset of the stimuli (Experiment 2) showed evidence of implicit sensitivity to both key membership and harmony in 4-year-olds. These components differed from the typical response elicited in older children and adults, but were consistent with other studies showing similar immature components in young children. In Chapter 3, I found that 4- and 5-year-old children demonstrated behavioural sensitivity to both key membership and harmony in a less demanding task than was used in Chapter 2, specifically, in a familiar song. In Chapter 4, I compared children who were or were not taking music lessons and found that musical experience accelerated enculturation to musical pitch structure. Together, these findings indicate that under some circumstances even 4-year-old children demonstrate behavioural sensitivity to

Western musical pitch structure, that implicit processes show sensitivity to Western musical pitch structure before this knowledge is demonstrated behaviourally, and that intensive musical experience accelerates musical acquisition.

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Preface

This thesis consists of studies that have been previously published or are under review for publication in scientific journals. Chapter 2 consists of a manuscript that is under review for publication. The author of the present thesis is the primary author of this manuscript, and was responsible for the experimental design and stimulus generation, data collection and analysis, and manuscript preparation. The thesis supervisor is the second author of this manuscript.

Chapters 3 and 4 present empirical findings of different aspects of a larger data set and thus overlap in content. Chapter 3 consists of a reprint of the following published journal article with permission from the University of California Press:

Corrigall, K. A., & Trainor, L. J. (2010). Musical enculturation in preschool children: Acquisition of key and harmonic knowledge. *Music Perception, 25,* 195-200. doi:10.1525/mp.2010.28.2.195

The author of the present thesis is the primary author of this article, and was responsible for the experimental design and stimulus generation, data collection and analysis, and manuscript preparation. The thesis supervisor is the second author of this manuscript.

Chapter 4 consists of a reprint of the following published journal article with permission from the New York Academy of Sciences:

Corrigall, K. A., & Trainor, L. J. (2009). Effects of musical training on key and harmony perception. *Annals of the New York Academy of Sciences, 1169,* 164-168. doi:10.1111/j.1749-6632.2009.04769.x

The author of the present thesis is the primary author of this article, and was responsible for the experimental design and stimulus generation, data collection and analysis, and manuscript preparation. The thesis supervisor is the second author of this manuscript.

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CHAPTER 1: Introduction

Music is ubiquitous in the life of a developing child. Caregivers sing lullabies to soothe distressed infants and playsongs to arouse interest and excitement in their young children (Rock, Trainor, & Addison, 1999; Trehub & Trainor, 1998), and music is often used as a teaching tool in school classrooms. Music is also present at important social gatherings such as weddings, funerals, and ritual ceremonies, as well as in everyday experiences such as visiting a shopping mall, listening to the radio, and watching television. Thus, children amass much informal musical experience and knowledge, simply by virtue of continual exposure to music in their day-to-day lives. At the same time, some children also acquire formal music experience by participating in music lessons. In this thesis, I examined the development of music perception skills that are acquired through informal experience with the music of one's culture as well as the effect of formal music training on these skills.

Perceptual Narrowing and Musical Enculturation

Cultural differences shape the way that individuals perceive the world. For example, *perceptual narrowing* occurs for aspects of both visual and auditory processing, whereby individuals become specialized at processing stimuli that occur regularly in their native environment compared to stimuli that they do not encounter very often. In the area of face perception, for example, young infants can discriminate between individual faces of their own race just as easily as between individual faces of a foreign race that they are rarely exposed to (Kelly et al., 2009; Kelly et al., 2007; Kelly et al., 2005), or even between individual faces of another species (e.g., Pascalis, de Haan, & Nelson, 2002); however, as infants accumulate experience with own-race faces in their daily environment, their discrimination of these faces improves, whereas their discrimination of faces from foreign races and other species worsens (Kelly et al., 2009, 2007, 2005; Pascalis et al., 2002). Perceptual narrowing is also evident in language development in the area of phoneme perception. Young infants can distinguish phonemic contrasts of foreign languages as well as their native language, whereas older infants become increasingly better at distinguishing between native phonemes and increasingly worse at distinguishing between foreign language phonemes that they rarely or never hear (e.g., Kuhl et al., 2006; Werker & Tees, 1984). Importantly, perceptual narrowing is driven by experience because exposure to non-native stimuli can delay the effect (e.g., Kuhl, Tsao, & Liu, 2003; Pascalis et al., 2005). Thus, in many ways infants begin life with a flexible system that adapts to the particular stimuli that they encounter in their native environment, but through experience, this system eventually becomes specialized for the processing of stimuli in familiar configurations.

In the domain of music perception, *musical enculturation* is a broader term than *perceptual narrowing* that is used to describe the acquisition of knowledge about the structure of music in one's native culture as well as specialized processing for aspects of that musical structure. Just as languages differ across cultures, so too do musical systems, and just as children learn the language that they are exposed to in their native environment, so too do they learn the musical system that they are exposed to in their culture. Importantly, enculturation occurs for many different aspects of music, as it does for many aspects of language. In language, for example, perceptual narrowing occurs in phonemic perception, but individuals also acquire knowledge about the phonotactic, morphological, and syntactic structure of their native language. Similarly, individuals become enculturated to different aspects of the temporal and pitch structures of their culture's music, such as metrical, tonal, and harmonic structures.

The Structure of Musical Systems Across Cultures

One way that musical systems differ across culture is in the type of metrical structures that are used in musical pieces. Meter is the periodic temporal structure in music that is organized hierarchically, related to what we tap our feet to or what we think of as "the beat". In some cultures, including those in which Western music prevails (e.g., in western Europe and much of North America), the vast majority of music is composed with metrical structures composed of simple-integer ratios that contain an isochronous pulse that is subdivided into two or three, as in a march or a waltz. However, in other cultures, such as in Bulgaria and Macedonia, metrical structures with complex-integer ratios are also used in which the pulse is periodic but not isochronous; for example, one complex meter might contain two beats of unequal length per measure where the first beat is subdivided into two but the second beat is subdivided into three. In this example, the subdivisions of the beat are isochronous, but the hierarchical level above these subdivisions (i.e., the beat) is not because the second beat would be 1.5 times longer than the first beat.

Hannon and Trehub (2005a) showed that for both simple-integer and complex-integer ratio metres, North American 6-month-old infants detected rhythmic changes that disrupted the metrical structure more easily than rhythmic changes that kept that structure intact, despite having little to no exposure to those complex meters. However, Hannon and Trehub (2005b) found that by 12 months, infants showed the same pattern as enculturated North American adults, namely a detection advantage for metrical structure-violating changes over metrical structure-preserving changes for simple-integer ratio meters but not for complex-integer ratio meters. Taken together, the results of these studies suggest that as North American infants gain increasing exposure to the simple meters of Western music, they become enculturated to these metrical structures and show processing biases for the familiar metrical structures in the same way that Western adults do. Thus, enculturated listeners develop specialized processing for the musical meters that they are exposed to, and they often lose their ability to discriminate between unfamiliar stimuli in unfamiliar meters, similarly to how perceptual narrowing occurs in face processing and speech perception. Furthermore, it is clear that experience drives enculturation to metrical structure because Bulgarian and Macedonian adults who were exposed to both types of meters throughout their life showed a similar unbiased pattern as 6-month-olds (Hannon & Trehub, 2005a), as did North American 12-month-olds who received two weeks of at-home passive exposure to music composed with complex-integer ratio meters (Hannon & Trehub, 2005b). Our daily exposure to the music of our culture therefore colours the way we perceive and experience music in general.

Another way that musical systems differ across culture is in their organization of pitch. Different musical systems use different scales, which are usually comprised of five to seven discrete pitch levels or notes. Scales differ in the particular notes that belong in the scale and hence the pitch interval distances between adjacent notes. Furthermore, many cultures use several different scales and thus an enculturated listener may become sensitive to several different pitch organizations. For example, the traditional music of Bali and Java is played on a set of instruments referred to as a *gamelan* and uses two different scales: the five-note equal-step *sléndro* scale, and the seven-note unequal step *pélog* scale in which only five of the seven notes are typically used within a particular performance. These scales are tuned differently from region to region within Bali and Java and sound very different from Western scales. By contrast, North Indian *ragas* are similar to Western music in that most are based on a set of 7 of 12 possible notes that are also tuned similarly to Western music; however, many more scales (referred to as *thats*) are used than in Western music.

In Western music, the major and minor scales are most often used as the bases for musical pieces, with the major scale being the most common (e.g., Huron, 2006; Schellenberg & von Scheve, 2012). Both types of scales are based on a division of the octave into a set of 12 equally spaced notes that form the chromatic scale, where each note belongs to a particular pitch class – a collection of notes that are separated by an octave (a doubling of the fundamental frequency) and that also share the same letter name (e.g., all of the Cs on the piano). The interval distance between adjacent notes in the chromatic scale is referred to as a semitone, which roughly corresponds to a 6% difference in fundamental frequency. The major scale can begin on any note of the chromatic scale and is composed of 7 of the 12 notes, but what characterizes this particular scale is the intervallic distance between adjacent notes: regardless of the starting note, the first three notes as well as the last four notes are each separated by a whole tone (equivalent to two semitones), whereas the third and fourth note are separated by a semitone, as are the seventh note of the scale and the octave equivalent of the first note. For example, the C major scale is composed of the notes C, D, E, F, G, A, and B, but does not include the remaining notes of the chromatic scale (e.g., C♯, B♭), and follows the major scale interval pattern: E and F are separated by a semitone, as are B and the octave equivalent of the starting note C, but all other adjacent notes are separated by whole tones. By contrast, the minor scale is based on the same 12 notes of the chromatic scale, but is characterized by a different intervallic pattern between adjacent notes.

Another aspect of musical structure that is related to the use of scales is the concept of *tonality*, which refers to the organization of each note of the scale around a central reference note. Similarly, the *tonal hierarchy* refers to the relative frequency, stability, and importance of notes within the scale. For example, the Balinese and Javanese *sléndro* scale is centred around a gong tone, and North Indian *ragas* are centred on a continual drone that sounds throughout a performance. In the Western major scale, the central reference note is always the first note of the scale, which is called the tonic. Western musical pieces exhibit tonality in that they are composed in a key that is based on a particular scale and named for the tonic of that scale. For example, a piece written in the key of C major is based on the C major scale, where the tonic is the note C. One aspect of musical enculturation that children acquire is knowledge of key membership, or knowing which notes belong in a key and which do not. Out-of-key notes are more rarely used in musical pieces, often as a way of adding musical interest, or to modulate to another key (when a piece of music shifts from one key to a different key). If an out-of-key note occurs unexpectedly, it is usually perceived as sounding wrong. Taking the key of C major as an example once again, notes such as C♯ and B♭ do not belong to the key of C and occurrences of these notes would usually be perceived as errors. Importantly, this knowledge must be abstract in nature because different musical pieces are composed in different keys, and so it is not enough to simply learn one set of absolute pitches; rather, children must learn the relative pitch pattern of intervals within a scale and be able to extract the tonal centre from a musical piece in order to understand implicitly which notes belong and which do not. Furthermore, this knowledge must be flexible enough to accommodate for important aspects of musical interest, such as the strategic use of out-of-key notes in certain situations, and for key modulation. Thus, part of becoming enculturated to the pitch structure of Western music involves developing a sophisticated implicit understanding of key membership.

For music to be pleasant, it likely has to strike a balance between complexity and simplicity in order for it to be perceived as interesting but not confusing. Thus, musical systems often exhibit rich complexity in one structural aspect, but compensate with simplicity in another aspect. One aspect of Western pitch structure that exhibits significant complexity is the use of *harmony*, which refers to the simultaneous combination of notes into chords and the hierarchical sequential organization of those chords. Western music may be unique in the world in its use of harmony, but this complexity in pitch structure is complemented by its use of relatively simple metrical structures and rhythms. In Western music, chords are usually composed of three or more notes and can be built on any note of a scale. Chords are named for their starting note and the intervallic relationship between that starting note and the remaining notes, or for the relationship between the starting note of the chord and the starting note of the scale to which it belongs. For example, in the key of C major, a chord built on the note C would include the notes C, E, and G, and would be called a C *major* chord because of the intervallic relationship between C and the other two notes (a four semitone difference between C and E, and a seven semitone difference between C and G); alternatively, this chord could be named with the roman numeral I because it is based on the first note of the C major scale. By contrast, a chord built on the note A in the key of C major would include the notes A, C, and E, and would be called an A *minor* chord because it demonstrates a *different* intervallic relationship between its starting note and the other two notes (a *three* semitone difference between A and C, and a seven semitone difference between A and E), or it could be referred to as a vi chord (denoted in lower case letters to indicate that it is a minor chord), as it is based on the sixth note of the C major scale. Thus, one part of harmonic knowledge is understanding which notes go together to form chords within a given key.

Another part of harmonic knowledge is understanding which notes and chords tend to follow others at different points in a musical piece. In this way, music exhibits a kind of syntax, similar to the syntactic structure of language. For example, the seventh note of the Western major scale (e.g., the note B in the key of C major) is often followed in melodies by the tonic above it (e.g., the note C in the key of C major). Musical tension is perceived during the seventh note, but this tension feels resolved when the seventh note moves to the tonic. Similarly, a V chord (also referred to as a dominant chord) is frequently followed by a I chord (tonic chord) at the end of Western musical phrases and this progression is also perceived as a shift from tension to relaxation or resolution. Although the V-I chord progression is the most common and most expected chord progression at the end of musical phrases, there are other chord progressions that occur less often at the end of phrases (e.g., the so-called "deceptive cadence" where a V chord is followed by a vi chord), and some that never end a phrase (e.g., a V chord followed by a vii˚ chord) (Huron, 2006). Harmonic expectations must be sophisticated enough to differ according to the genre of music (see Huron, 2006, pp. 252-254), and Western enculturated listeners are even sensitive to the harmonic relationships that are implied by a single melody line (e.g., Trainor & Trehub, 1992, 1994). Thus, enculturated listeners develop a complex set of expectations for which notes and chords follow others in Western music.

Expectation and Emotional Meaning in Music

> "…what a musical stimulus or series of stimuli indicate and point to are not extramusical concepts and objects but other musical events which are about to happen. That is, one musical event (be it a tone, a phrase, or a whole section) has meaning because it points to and makes us expect another musical event." (Meyer, 1956, pp. 35)

One reason that musical enculturation is so integral to music perception is that it may form the basis for perceiving meaning and emotion in music, therefore supporting what many believe is music's core function. In the 1950s, Leonard Meyer (1956) argued that emotion and meaning in music arise primarily through a listener's expectations that have been shaped by cultural experiences, and that music that does not produce expectations (for example, because its underlying structure is unfamiliar to the listener) is meaningless. Thus, Meyer's position suggested that emotion and meaning in music could only be experienced in enculturated listeners who have internalized the underlying structure of the music of their culture. Although this stance is probably too strong, culturally-formed musical expectations are clearly important in the experience of music. Many years later, David Huron (2006) built on Meyer's ideas, developing a theory on how expectations evoke emotion in general and exploring how his theory would apply to music. Importantly, both theories suggested that the ebb and flow between tension – produced through unexpected or infrequent musical events – and relaxation – produced through expected or frequent musical events – is fundamental to musical meaning and musical interest.

Since Meyer's (1956) original proposal, empirical evidence has been gathered on the emotional responses to expected compared to unexpected musical events. For example, Sloboda (1991) was the first to show that particular intense emotional responses were associated with particular musical features, such as pleasant "chills" or "shivers down the spine" in response to an unexpected but musically appropriate harmony. Later studies showed that the intensity of chills in response to music was associated with dopamine release in the nucleus accumbens (Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011), autonomic nervous system arousal as measured by electrodermal activity, heart and respiration rate, temperature, and blood volume pulse (Salimpoor, Benovoy, Longo, Cooperstock, & Zatorre, 2009), and activity in several brain regions that are important in experiencing emotion and reward such as the amygdala, hippocampus, ventral striatum, dorsomedial midbrain, and ventromedial prefrontal cortex (Blood & Zatorre, 2001). Other research has demonstrated that harmonically unexpected chords, such as those that violate key structure, are perceived as having more tension and elicit greater electrodermal activity

(Steinbeis, Koelsch, & Sloboda, 2006), and these chords are rated as sounding less pleasant and elicit a greater amygdala response (Koelsch, Fritz, & Schlaug, 2008) than harmonically expected chords. Because musical expectations frequently depend on culturally acquired musical knowledge, the results of these studies support the crucial role of enculturation in musical meaning and emotion perception.

Behavioural Sensitivity to Key Membership and Harmony in Western Adult Listeners

By adulthood, even musically untrained Western listeners have developed a great deal of sensitivity to the pitch structure of the music of their culture. One way that musical enculturation can be tested behaviourally is by examining whether individuals show biased processing for the aspects of music that conform to the structure of their culture's music compared to aspects that do not. Several different methods have been used to demonstrate that Western adults have implicit knowledge of key membership and harmony. Using change detection methods, researchers have shown that untrained Western adults can better detect a change in a sequence that is based on a familiar mode (major or minor) than one that is based on a scale that they are not familiar with (Lynch, Eilers, Oller, & Urbano, 1990; Trehub, Schellenberg, & Kamenetsky, 1999). These results suggest that adults have implicit knowledge of key membership because their change detection is facilitated for musical stimuli composed in a familiar mode. In a different kind of change detection method, other researchers have shown that adults are also better at detecting changes to a melody composed in a major key when the changed note goes outside the key or when it remains in the key but violates the implied harmony at that point than when it conforms to both the key of the melody as well as the implied harmony (Trainor & Trehub, 1992, 1994). Implicit tasks using reaction time measures have also been widely used to test adults' knowledge of Western pitch structure. In these tasks, adults are typically asked to make speeded binary judgments about an aspect of the stimuli that is unrelated to key membership or harmony, such as whether a final note or chord was mistuned, or what timbre it was played in. The rationale is that adults should be faster to respond to the unrelated aspect if the note or chord fits their enculturation-based expectations than if the note or chord violates their expectations by going outside the key or going outside of the expected harmony at that point. Using this method, researchers have demonstrated that untrained Western adults are sensitive to both key membership and harmony (e.g., Bigand & Pineau, 1997; Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003; Tillmann, Bigand, & Pineau, 1998; see Bigand & Poulin-Charronnat, 2006 for a review).

Another way that adults can demonstrate enculturation is by their explicit judgments about the appropriateness or pleasantness of notes and chords in a musical context. The method that has been most widely used to elicit explicit judgments from listeners is the probe tone method developed by Krumhansl and her colleagues (see Krumhansl, 1990), in which participants are presented with a musical prime sequence and then asked to rate how well a probe tone, chord, or pair of probe tones or chords fits the sequence. Researchers have demonstrated that both musically trained and untrained Western adults' judgments reflect a keen sensitivity to key membership and harmony: they typically rate out-of-key notes and chords lower than in-key notes and chords, but they also rate individual in-key notes and chords in a manner that reflects the tonal hierarchy (Cuddy & Badertscher, 1987; Krumhansl, 1990; see Krumhansl & Cuddy, 2010 for a review). For example, the tonic note or chord is usually rated as sounding the best, followed by the dominant.

Musical Experience and Enculturation to Pitch Structure

It is perhaps not surprising that there is a correlation between enculturated listeners' ratings of the most expected tones following a prime and the actual frequency of occurrence of those tones in musical pieces (Krumhansl, 1990). Interestingly, it appears that adults can even show some sensitivity to the structure of unfamiliar music from a foreign culture by using frequency distribution of tones within the immediate context of a melody (e.g., Castellano, Bharucha, & Krumhansl, 1984; Kessler, Hansen, & Shepard, 1984). However, enculturated listeners tend to show more sophisticated sensitivity to more subtle aspects of the tonal hierarchy than unenculturated listeners. For example, in Western music, the dominant is by far the most frequently played note, even more frequent than the tonic (Aarden, 2003 described in Huron, 2006). However, enculturated listeners consistently favour the tonic over the dominant in their ratings of phrase-final notes (Krumhansl, 1990). To explain these results, Aarden showed that there is a much higher correlation between reaction times to phrase-final notes in a melody and the actual frequency distribution of phrase-final notes in Western music compared to the overall frequency distribution of notes within Western musical pieces. In other words, enculturated listeners are not only sensitive to *what* should occur, but they are also sensitive to *when* it should occur. Cross-cultural research has shown that listeners rate phrase-final notes in culturally foreign music according to the statistical distribution of notes within the immediate context of the prime melody, whereas enculturated listeners' ratings additionally follow the tonal hierarchy, for example, by giving the highest ratings to the gong or drone tone even if it occurred less frequently than other notes in the prime melody (e.g., Castellano et al., 1984; Kessler et al., 1984).

It might be expected that trained musicians should perform differently than non-musicians on tests of sensitivity to key membership and harmony because they acquire explicit knowledge of music theory, and because they have amassed much more exposure to music. However, the evidence for this prediction is mixed. Many probe tone studies have shown that both musicians and non-musicians show sensitivity to each level of the tonal hierarchy, although musicians tend to show greater differentiation between different levels of the hierarchy (e.g., Frankland & Cohen, 1990; Jordan & Shepard, 1987; Krumhansl & Shepard, 1979; Steinke, Cuddy, & Holden, 1997). However, other probe tone studies have failed to find any influence of musical training (e.g., Brown, Butler,

& Jones, 1994; Cuddy & Badertscher, 1987). Similarly, there is a general tendency for musically trained individuals to be overall faster and more accurate on implicit reaction time tasks than non-musicians, but there is very little evidence that musical training affects the size of the harmonic priming effect (e.g., Bigand et al., 2003; Bigand, Tillmann, Poulin, D'Adamo, & Madurell, 2001; Bigand, Tillmann, Poulin-Charronnat, & Manderlier, 2005; Poulin-Charronnat, Bigand, Madurell, & Peereman, 2005; Schellenberg, Bigand, Poulin, Garnier, & Stevens, 2005). Together, these results strongly suggest that tonal and harmonic expectations do not require formal music training. Moreover, it appears that the effects of music training on sensitivity to key membership and harmony are small and subtle. At the same time, it remains unknown whether music training has a larger effect on musical enculturation early in development, before children have fully acquired this sensitivity. Chapter 4 of this thesis addresses this possibility.

The Development of Sensitivity to Key Membership and Harmony in Childhood

There is no evidence to date that Western infants are sensitive to key membership or harmony. Although it can be a challenge to develop methods that can assess infants' knowledge of pitch structure, change detection methods have proven to be a useful tool in this regard. In one study, 6-month-old infants detected changes to melodies based on Western major, Western minor, and Javanese *pélog* scales equally well, whereas Western adults performed better with the familiar Western melodies (Lynch et al., 1990). Similarly, another study found that 9-month-old infants were better able to detect a change in a Western major scale and in an unfamiliar unequal-step scale than in an unfamiliar scale in which all intervals between adjacent notes were of equal size (Trehub et al., 1999). Because infants were no better at detecting changes to the familiar Western scales compared to the unfamiliar scales, these findings suggest that infants have not yet acquired sensitivity to Western key structure. Using a different kind of change detection task, Trainor and Trehub (1992) found that infants detected changes to a Western major melody equally well whether those changes went outside the key or remained in-key and in-harmony. Because adults showed better detection of changes that violated the key structure of the melody than changes that did not, these results provide converging evidence that infants are not yet sensitive to Western pitch structure.

The results of these studies suggest that infants do not yet have implicit knowledge of Western key membership or harmony. However, recent research has shown that after participating in 6 months of active infant music classes, 12-month-old infants prefer listening to tonal over atonal music (Gerry, Unrau, & Trainor, 2012; Trainor, Marie, Gerry, Whiskin, & Unrau, 2012), suggesting that enriched musical experiences in infancy may accelerate enculturation to musical pitch structure. Furthermore, even infants who do not participate in specialized music classes exhibit processing biases for some aspects of pitch structure. For example, infants are better able to detect a change in scales that are composed of unequal rather than equal steps (Trehub et al., 1999). Infants also typically prefer consonant to dissonant intervals (Masataka, 2006; Trainor & Heinmiller, 1998; Trainor, Tsang, & Cheung, 2002; Zentner & Kagan, 1998), although this preference may not extend to chordal stimuli (Plantinga & Trehub, 2012), and they process pitch in a relative rather than an absolute manner (Plantinga & Trainor, 2005).

These biases and preferences may provide a foundation for later enculturation to key membership and harmony because they are fundamental buildings blocks for more sophisticated knowledge. For example, a processing advantage for unequal-step scales over equal-step scales may prepare an infant for later acquisition of the particular unequal-step pattern of the scales of their culture. Dissonance and consonance are thought to be related to harmonic tension and relaxation respectively; thus, a preference for consonance may form the basis from which harmony perception develops. Finally, processing pitch according to a relative rather than an absolute pitch code is essential for music perception: it not only allows for recognition of a melody across transposition, but it also allows abstract knowledge of key membership and harmony to develop in the first place, given its emphasis on pitch patterns.

If Western adults have become fully enculturated to the pitch structure of the music of their culture but infants have not yet acquired this sensitivity, then it is reasonable to ask when this skill develops in childhood. Unfortunately, few studies have been conducted with children to examine their knowledge of key membership and harmony, especially in children below the age of 6 years.

Despite the scarcity of research on this important aspect of development, one key finding to emerge from previous research is that children first acquire knowledge of key membership, and then later develop the more sophisticated ability to perceive harmonic relationships. In one change detection study, 4- and 5-year-old children were better at detecting a changed note in a melody that conformed to the major scale than in a melody that did not, suggesting biased processing for Western key structure (Trehub, Cohen, Thorpe, & Morrongiello, 1986). In another change detection study, 7-year-olds and adults could easily detect changes to a Western major melody that went outside the key or that remained in key but did not fit the appropriate implied harmony at that point, but they had more difficulty detecting changes that fit both the key of the melody and the implied harmony (Trainor & Trehub, 1994). By contrast, 5-year-olds showed evidence of only detecting changes that violated key structure, suggesting that they had knowledge of key membership but not harmony. In an implicit reaction time study using chordal rather than melodic stimuli, Schellenberg and colleagues showed that 6- to 7-year-olds are sensitive to harmony (Schellenberg et al., 2005). Together, these studies suggest that children understand implicitly which notes and chords belong in a key and which do not before they understand the more nuanced hierarchical structure of notes and chords within a given key. Still, some unanswered questions remain, such as whether the developmental timeline for knowledge of key membership and harmony differs for melodic compared to chordal stimuli, whether younger children can demonstrate partial knowledge of the pitch structure of Western music, and whether biased processing for aspects that conform to Western music structure implies that children consciously perceive violations to the expected structure as sounding surprising or even wrong, as enculturated adults do.

To examine children's explicit, evaluative judgments of the appropriateness of the notes of the chromatic scale, several studies have used a probe tone method that has been simplified for use with children, for example, by reducing the rating scale from a 7-point Likert scale to a 3-point scale comprised of a sad, neutral, and happy face. These studies have shown that by approximately 6 years of age, children exhibit adult-like sensitivity to the tonal hierarchy, giving the highest ratings to the notes of the tonic triad, followed by other in-key notes, and by giving the lowest ratings to out-of-key notes (e.g., Cuddy & Badertscher, 1987; Speer & Meeks, 1985). However, there appears to be some further development of this sensitivity from 6 to 10 years (Krumhansl & Keil, 1982). Yet no studies to date have tested whether children below the age of 6 years can make explicit judgments that reflect knowledge of key membership and harmony. Furthermore, it is unknown whether young children can make explicit judgments about the appropriateness of chordal stimuli.

Methodological Issues Associated with Testing Young Children's Music Perception

One reason for the scarcity of research on children's music perception between infancy and school age is that there has been a lack of age-appropriate methods that are suitable for use with toddlers and preschool-aged children. The conditioned head turn and head turn preference methods that are typically used with infants are no longer appropriate for older children who can provide verbal as well as nonverbal (e.g., pointing) responses, and other methods that are typically used with adults – such as the probe tone method, change detection, and reaction time tasks – require many trials and therefore long bouts of sustained attention, which can be very difficult for young children. Adult methods also tend to require behaviours that are too sophisticated for young children to perform, such as using ratings scales and making speeded judgments. Furthermore, existing methods have all presented auditory stimuli with no accompanying visual display, which make it difficult to engage children's full attention, especially for children in today's society who live in a multimedia-rich environment. Thus, there is a need for more age-appropriate behavioural methods that can be used to examine the development of young children's knowledge of Western musical pitch structure.

Although it important to develop appropriate behavioural methods to understand what children consciously perceive when listening to music that does or does not conform to Western pitch structure, neurophysiological methods such as electroencephalography (EEG) can be used to assess implicit musical knowledge in young children. In adults, an event-related potential (ERP) component referred to as the early right anterior negativity (ERAN) is typically elicited to chords that violate Western key or harmony structure (e.g., Koelsch, Gunter, Friederici, & Schröger, 2000; Koelsch et al., 2001; see Koelsch, 2009 for a review). The ERAN has also been found in children as young as 5 years of age in response to strong violations to key membership (Koelsch et al., 2003) and to harmony (Jentschke, Koelsch, Sallat, & Friederici, 2008); however, there are no published data on children younger than 5 years. Although neurophysiological methods require many trials, the ERAN is reliably elicited under passive listening conditions where children can focus their attention on a silent movie while musical stimuli play in the background. Thus, EEG can be an ideal method to study young children's implicit musical knowledge.

Outline and Significant Contributions of Thesis Experiments

Chapters 2, 3, and 4 are aimed at addressing many of the methodological issues that have limited the study of music perception in young children, and to further refine our understanding of the development of enculturation to musical pitch structure. Experiment 1 in chapter 2 presents a novel method for testing 4- and 5-year-olds' explicit knowledge of key membership and harmony in unfamiliar chord sequences and melodies, in which children watched videos of puppets playing songs that did or did not conform to Western pitch structure and awarded prize ribbons to the puppets that played the best songs. As this procedure was very engaging for children and required many fewer trials than existing methods, I was able to study younger children than has been possible with the probe-tone method. Furthermore, the development of sensitivity to key membership and harmony could be directly compared in the context of both natural chord progressions and simple melodies, using more ecologically valid stimuli than previous experiments that used scales or triads as stimuli. Finally, the generalizability of the results was improved compared to previous studies because a different musical sequence was presented on each trial, ensuring that children's responses reflected their abstract knowledge of Western pitch structure rather than the accumulation of knowledge about the particular sequence presented within the experiment.

Chapters 3 and 4 present a second novel method for testing young children's explicit knowledge of key membership and harmony in a familiar song in three contexts: the melody alone, the melody accompanied by chords, and the chords alone. On each trial, children decided if a puppet's song was played correctly or incorrectly or if it sounded good or bad using happy-face and sad-face hand signs. Using this method, I was able to demonstrate behavioural sensitivity to both key membership and harmony in the youngest children to date (i.e., 4-year-olds) in the context of a familiar song, suggesting that young children may have partial knowledge of Western pitch structure before they become fully enculturated listeners. Furthermore, through the use of a longitudinal design, chapter 4 shows that experience drives enculturation. Specifically, there were no pre-existing differences in sensitivity to key membership and harmony at the first measurement in children who had just begun music lessons compared to children who were not enrolled in lessons, but after approximately one year of lessons, musically trained children outperformed their nonmusically trained peers.

Experiment 2 in chapter 2 was aimed at testing implicit or pre-conscious knowledge of Western pitch structure in 4-year-old children who did not demonstrate behavioural sensitivity to either key membership or harmony in unfamiliar but typical Western sequences (Experiment 1 of chapter 2). Using EEG, we recorded children's ERPs to chord sequences and melodies that ended either according to Western harmony rules, or that ended on a chord or note that violated key membership or harmony. We found an immature but ERAN-like response to violations of key and harmony in chord sequences. These results converged with the behavioural findings of Chapters 3 and 4 suggesting that children as young as 4 years of age have partial or implicit knowledge of key membership and harmony.

This thesis contributes to our understanding of the acquisition of enculturation to musical pitch structure – a fundamental aspect of musical knowledge that plays an important role in the formation of musical expectations, and therefore, in the perception of musical meaning and emotion. I provide evidence for sensitivity to key membership and harmony in the youngest children tested to date, using both explicit and implicit measures as well as more ecologically valid stimuli (chord progressions and melodies) than have been used to date. Furthermore, the thesis experiments provide two unique methods for testing musical knowledge in preschoolers and toddlers that can be adapted to study other areas of music perception, such as knowledge of the temporal structure of music. More generally, this thesis contributes to our understanding of music as both a fundamental aspect of culture and human behaviour, and an important but understudied component of the natural development of a child.

CHAPTER 2: Enculturation to musical pitch structure in young children: Evidence from behavioral and electrophysiological methods

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Preface

Enculturation to musical pitch structure is an important component of the normal musical development of a child. Knowledge of key membership and harmony facilitates the perception of expectation-related emotion in music, allowing music to take on a deeper meaning. Furthermore, musical enculturation occurs naturally in every typically-developing child, without the need for formal training or instruction. In this way, musical enculturation is acquired in a similar manner to how children learn language: by being immersed in the sounds that permeate in a particular culture. For example, even musically-untrained Western adults exhibit processing biases for musical sequences that conform to Western musical structure compared to sequences that violate that structure (see Bigand & Poulin-Charronnat, 2006 for a review), and their ratings reflect sophisticated knowledge of which notes and chords fit best at particular places in a musical phrase (see Krumhansl & Cuddy, 2010; Krumhansl, 1990 for reviews). A particular ERP component that reflects processing of musical syntax, the ERAN, is also reliably elicited to violations of Western musical pitch structure in non-musician adults (see Koelsch, 2009 for a review), suggesting that untrained Western adults process musical syntax implicitly.

Despite the importance of key membership and harmony knowledge in music perception, there has been very little research on how and when this knowledge is acquired. Several studies have successfully adapted adult methods such as probe-tone rating scales and reaction time tasks for use with school-aged children (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Schellenberg et al., 2005; Speer & Meeks, 1985), but a lack of age-appropriate methods has impeded the study of these abilities in younger children. Furthermore, there is a need for a comprehensive examination of children's developing knowledge of musical pitch structure. For example, no previous studies have compared children's sensitivity to key membership or harmony in both single-line melodies as well as chord sequences; rather, research to date has either tested knowledge within single-line melodies, scales, or triads (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Speer & Meeks, 1985; Trainor & Trehub, 1994; Trehub et al., 1986), or within chordal sequences (e.g., Jentschke et al., 2008; Koelsch et al., 2003; Schellenberg et al., 2005). A few studies have also failed to differentiate between sensitivity to violations of key membership compared to violations of harmony (e.g., Jentschke et al., 2008; Koelsch et al., 2003; Schellenberg et al., 2005), or have only tested one of these violation types (e.g., Jentschke et al., 2008; Koelsch et al., 2003; Trehub et al., 1986).

Furthermore, only a few studies have used ecologically valid melodies or chord sequences (e.g., Jentschke et al., 2008; Koelsch et al., 2003; Schellenberg et al., 2005; Trainor & Trehub, 1994) rather than scales and triads (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Speer & Meeks, 1985; Trehub et al., 1986). Finally, most previous behavioural studies have presented the same sequence or sequences repeatedly (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Speer & Meeks, 1985; Trainor & Trehub, 1994; Trehub et al., 1986), limiting the generalizability of the results.

The experiments of Chapter 2 were aimed at addressing these issues in order to provide a comprehensive examination of preschoolers' knowledge of key membership and harmony. In Experiment 1, I designed a novel task that was age-appropriate and engaging enough to maintain young children's attention, testing knowledge of musical pitch structure within both simple melodies as well as in chord sequences. On each trial, children watched two videos of puppets playing the piano, and decided which puppet played the best song. One puppet's song followed Western key and harmony rules, and the other puppet's song violated those rules in one of three ways. Two of these violations tested knowledge of key membership: in the atonal condition, the deviant sequence did not establish any particular key, and in the unexpected key condition, only the last note or chord of the deviant sequence violated key membership. The third condition (unexpected harmony condition) tested knowledge of harmony, in which the last note or chord remained in key but violated the most expected harmony at that point. Because each child was presented with a different unfamiliar sequence on each trial, the results could be generalized to other typical Western major melodies and chord progressions. Furthermore, the sequences were highly controlled such that the simple acoustic frequency of particular notes or chords could not predict the most harmonically appropriate target ending. Thus, the stimuli used in this experiment were designed as part of a conservative test of children's knowledge of key membership and harmony because only abstract tonal knowledge could be used to form culturally appropriate expectations; acoustic frequency cues did not provide sufficient information. The results of this experiment revealed that 5-year-old children demonstrated knowledge of key membership but not harmony, whereas 4-year-olds did not demonstrate knowledge of either.

Experiment 2 was designed to examine implicit knowledge in 4-year-old children who did not yet exhibit behavioural sensitivity to key membership and harmony. Children's ERP responses were recorded to a subset of stimuli from Experiment 1, and we compared the response to target notes or chords that did or did not violate Western key or harmony rules. This age group was younger than in any published research to date, and the study was the first to test ERP responses to both chords and melodies as well as to both key membership and harmony in children. We found that 4-year-old children showed neurophysiological sensitivity to both key membership and harmony within chord sequences but not melodies. Interestingly, children's ERP response to these violations differed from the ERAN response that is typically elicited in adults, suggesting that it was an immature version of this response.

In summary, this research suggests that sensitivity to Western musical pitch structure improves between 4 and 5 years of age, and that implicit sensitivity to Western musical pitch structure precedes behavioural demonstrations of that sensitivity.

Abstract

Children learn the structure of the music of their culture similarly to how they learn the language to which they are exposed in their daily environment. Furthermore, as with language, children acquire this musical knowledge without formal instruction. Two critical aspects of musical pitch structure in Western tonal music are key membership (understanding which notes belong in a key and which do not) and harmony (understanding which notes combine to form chords and which notes and chords tend to follow others). The early developmental trajectory of the acquisition of this knowledge remains unclear, in part because of the difficulty of testing young children. In two experiments, we investigated 4- and 5-year-olds' enculturation to Western musical pitch using a novel age-appropriate and engaging behavioral task (Experiment 1) and electroencephalography (EEG; Experiment 2). In Experiment 1 we found behavioral evidence that 5-year-olds were sensitive to key membership but not to harmony, and no evidence that 4-year-olds were sensitive to either. However, in Experiment 2 we found neurophysiological evidence that 4-year-olds were sensitive to both key membership and harmony. Our results suggest that musical enculturation has a long developmental trajectory, and that children may have some knowledge of key membership and harmony before that knowledge can be expressed through explicit behavioral judgments.

Introduction

Sophisticated musical knowledge is often attributed solely to accomplished musicians, but studies indicate that non-musicians possess considerable implicit musical knowledge. Even adults who have never played a musical instrument can typically tap to a beat, sing a familiar song, detect a wrong note in an unfamiliar piece of music from their culture, and experience the subtle emotions conveyed by music (Jackendoff & Lerdahl, 2006; Miller, 2000). Furthermore, children acquire knowledge of the specific musical structure of their culture through everyday exposure, similar to the way that they learn their native language. In contrast to language, however, little is known about musical enculturation in preschool children. In two experiments, we examined the development of enculturation to two aspects of Western pitch structure: key and harmony.

Young infants are already sensitive to some aspects of pitch structure, which suggests that they are either born with processing biases for particular musical features, or that they acquire these biases with little exposure to music. Interestingly, musical predispositions tend to involve features that are relatively universal across musical systems (Hannon & Trainor, 2007). For example, young infants prefer consonant to dissonant musical intervals (Trainor & Heinmiller, 1998; Trainor, Tsang, & Cheung, 2002; Zentner & Kagan, 1998), including 2-day-old hearing infants of deaf parents (Masataka, 2006). Furthermore, infants more readily process melodies according a relative rather than an absolute pitch code, an ability that enables melody recognition across transposition (Plantinga & Trainor, 2005), and they more readily process scales with unequal-sized than equal-sized intervals (Trehub, Schellenberg, & Kamenetsky, 1999). Thus, before enculturation is evident, infants are already sensitive to basic aspects of musical pitch.

Sensitivity to features that are specific to a musical system depends on experience with that musical system. Most musical systems use scales, but the particular notes and intervals used vary across cultures. Thus, just as infants learn the particular phonemes, words and syntactic rules that are specific to their native language, so too do they learn the particular scale, key, and harmonic structures of the music of their culture. This implicit knowledge is likely acquired using domain-general processes such as statistical learning. Indeed, research has shown that infants can extract statistical information from both syllable (Saffran, Aslin, & Newport, 1996) and tone (e.g., Saffran, Johnson, Aslin, & Newport, 1999) sequences.

The major scale is the most common scale on which Western musical pieces are based. This scale is composed of 7 of the 12 possible pitch classes of the chromatic scale, which is created by dividing the octave into 12 equal semitone (6% pitch difference) intervals. A major scale consists of the intervals tone, tone, semitone, tone, tone, tone, semitone, where a tone equals two semitones. The scale can begin on any one of the 12 possible pitch classes and is named for its starting note. For example, the key of C major is based on the C major scale, which begins on the note “C” and includes the notes C, D, E, F, G, A, and B. Knowledge of key membership involves understanding which notes belong to the scale on which a musical piece is based and which do not (for example, the note D-flat does not belong to the key of C major).

By contrast, harmony perception requires finer-grained knowledge of the hierarchical organization of notes and chords within a key. This knowledge includes implicitly understanding how typical chords are built and which notes and chords tend to follow others in a musical piece, as well as acquiring sensitivity to the relative frequency and stability of different notes and chords within a key. In Western music, chords can be built on any note of the scale by combining the starting note with the third and fifth notes above it; thus, a chord built on the first note of the C major scale (referred to as the tonic chord) would include the notes C, E, and G, whereas a chord built on the fifth note (referred to as the dominant chord) would include the notes G, B, and D.

Chord sequences follow probabilistic syntactic rules. For example, a phrase ending with a dominant chord followed by a tonic chord is perceived as sounding complete. The tonic chord is typically the most frequently occurring chord in a musical piece, and it is perceived as the most important and stable sounding (Krumhansl, 1990). Harmony perception therefore involves an understanding of the statistical regularities of different notes and chords within a key, as well as expectations for which notes and chords follow others. It is well known that even musically untrained Western adults are sensitive to both key membership and harmony (for reviews, see Bigand & Poulin-Charronnat, 2006; Krumhansl, 1990; Krumhansl & Cuddy, 2010), but the developmental acquisition of this implicit knowledge has been understudied.

Young infants do not appear to be sensitive to key membership or harmony. For example, infants of approximately 9 to 11 months of age perform equally well at detecting changes to musical stimuli that do or do not conform to Western pitch structure, whereas older children and adults show an advantage for Western stimuli (Trehub, Cohen, Thorpe, & Morrongiello, 1986; Trehub et al., 1999). Furthermore, 8-month-olds detect out-of-key and in-key changes to a Western melody equally well, whereas adults are better at detecting out-of-key changes (Trainor & Trehub, 1992). There is evidence that with music training during infancy, some preliminary enculturation to musical pitch structure is evident by 12 months of age (Gerry, Unrau, & Trainor, 2012; Trainor, Marie, Gerry, Whiskin, & Unrau, 2012); however, the developmental trajectory for enculturation to key membership and harmony in the majority of children who do not take formal music classes remains unknown.

Research examining musical development in children has used three basic methodologies: first, asking for explicit judgments about musical passages that fit or do not fit Western key and harmony rules; second, examining processing biases (using implicit measures) for music that does or does not conform to Western pitch structure; and third, examining whether notes and chords that do or do not violate Western key and harmony rules elicit different electrophysiological brain responses. Explicit judgments are significant because they can indicate children's conscious, evaluative perceptions of music. Implicit tasks and electrophysiological measures are important because they can reveal implicit or pre-conscious knowledge in individuals who cannot yet make evaluative decisions regarding how good or bad a note or chord sounds in a musical piece.

Studies of whether children's explicit judgments reflect knowledge of key membership and harmony have used Krumhansl's (1990) probe-tone technique whereby listeners rate how good or bad the last note or two (probe tones) of a melody or chord sequence sound across trials where the probe tone(s) do or do not violate different aspects of musical pitch structure. The youngest children tested (6-year-olds) with this method demonstrated sensitivity to key membership and harmony by giving the highest ratings to notes that belonged to the tonic chord and by giving the lowest ratings to notes that fell outside of the key of the melody (e.g., Cuddy & Badertscher, 1987; Speer & Meeks, 1985), although there is also evidence that this sensitivity continues to develop beyond 6 years of age (Krumhansl & Keil, 1982). Although the probe-tone method shows that enculturated listeners can make explicit judgments about their musical knowledge, rating scales are difficult to use with preschool children because they tend to choose the extreme ends of a scale regardless of the number of response options (e.g., Chambers & Johnston, 2002). Furthermore, the task usually requires participants to complete many trials, which is beyond the attentional limits of most young children.

To obtain explicit judgments without using rating scales, other studies have asked participants to make binary decisions about musical stimuli. For example, Corrigall and Trainor (2010) found that 4- to 5-year-old children judged a familiar song (i.e., *Twinkle Twinkle Little Star)* that ended correctly as sounding "right" or "good" significantly more often than when it ended outside of the key or outside of the most expected harmony. These results suggest that young children can demonstrate knowledge of the musical pitch structure of their culture in certain situations, such as when the musical passages are familiar, although it remains unknown whether this knowledge generalizes to unfamiliar Western musical passages. Nevertheless, the findings also suggest that preschoolers' explicit knowledge of musical structure can be assessed with a two-alternative forced choice method. In the present research, we implemented this type of task to examine children's sensitivity to key membership and harmony in unfamiliar but conventional Western musical sequences.

In the domain of implicit tasks, children's musical enculturation has been examined with change detection procedures. For example, Trehub et al. (1986) showed that 4- and 5-year-olds were better able to detect a semitone change in a Western melody than in a non-Western melody, suggesting that they had some knowledge of key membership. Similarly, Trainor and Trehub (1994) showed that 5-year-olds were only better able to detect a changed note in a Western melody that went outside the key compared to a change that remained in the key, whereas 7-year-olds and adults further differentiated among in-key notes, detecting out-of-harmony changes better than changes that remained in-harmony. These results suggest that 5-year-olds are sensitive to key membership and that 7-year-olds have additionally acquired implicit knowledge of harmony. Using a different type of implicit task that has been used extensively with adults (e.g., Bigand & Pineau, 1997; Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003; Tillmann, Bigand, & Pineau, 1998), Schellenberg, Bigand, Poulin-Charronnat, Garnier, and Stevens (2005) found that 6- to 11-year-olds judged an unrelated aspect of the final chord in a sequence (e.g., whether it was played in a piano or trumpet timbre) faster and more accurately when it was harmonically appropriate than when it was a less expected and less stable chord. These results suggest that children as young as 6 years of age automatically form harmonic expectations that influence their processing of music even when harmonic appropriateness is irrelevant to the task at hand. The advantage of implicit tasks such as change detection and reaction time is that they have the potential to reveal knowledge that might not otherwise be detected by explicit tasks. However, implicit tasks also typically require many trials, limiting their usefulness with young children. Furthermore, preschoolers are typically not able to do the speeded judgments required in reaction time tasks. Thus, these types of implicit tasks can be impractical for preschoolers.

Finally, another way to tap implicit or pre-conscious knowledge is by recording electroencephalography (EEG) and analyzing event-related potential (ERP) responses to stimuli that do or do not violate key membership and harmony rules. In adults, violations to musical pitch structure in chordal stimuli elicit an early negativity (typically with a peak latency of 150 to 180 ms in adults) found in right anterior regions, termed the early right anterior negativity (ERAN; see Koelsch, 2009 for a review). The ERAN is thought to reflect syntactic processing and to rely on long-term musical syntactic knowledge, similarly to the early left anterior negativity (ELAN) that is elicited by syntactic violations in language (e.g., Friederici, 2002). The ERAN is larger in 11-year-old children who have taken music lessons compared to non-musician children (Jentschke & Koelsch, 2009), suggesting that it strengthens with further enculturation. Furthermore, the ERAN is present even when participants are not required to attend to the musical stimuli, making it an ideal component to study in young children. Research has shown that the ERAN can be elicited in response to strong violations to key structure (Koelsch et al., 2003) or to harmonic violations (Jentschke, Koelsch, Sallat, & Friederici, 2008) in children as young as 5 years of age, suggesting that 5-year-olds have some sensitivity to both key membership and harmony. A later component, the N5, is also elicited in response to musical syntactic violations under certain conditions, but is thought to be less automatic and more subject to attentional focus than the ERAN (e.g., Koelsch, Gunter, Friederici, & Schröger, 2000; Koelsch & Siebel, 2005; Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005). Although there are several limitations to using ERPs with children, such as the need for a large number of trials and the requirement that children remain fairly still, the fact that the ERAN can be elicited during a passive listening situation makes this method promising for use with preschoolers. Thus, we also conducted an EEG experiment to examine sensitivity to key membership and harmony in preschoolers whose explicit judgments in the two-alternative forced choice task did not yet reveal any knowledge of Western musical pitch structure.

In the present research, our first goal was to design an engaging and age-appropriate behavioral task that would elicit explicit judgments that reflected children's knowledge of key membership and harmony in unfamiliar Western music. Our second goal was to examine implicit or pre-conscious knowledge in younger children whose explicit judgments did not yet reveal any evidence of enculturation to Western musical pitch structure. We also sought to examine these skills in single-line melodies and in chord progressions, because enculturation to musical pitch has not yet been compared across these two contexts in children. In Experiment 1, we asked 4- and 5-year-olds to make explicit binary judgments about unfamiliar musical stimuli that did or did not fit Western musical pitch structure. In Experiment 2, we examined 4-year-olds' ERP responses to a subset of the same stimuli.

Experiment 1

Four- and five-year-olds watched videos of puppets playing the piano and judged which of two puppets deserved a prize. On each trial, one puppet's song followed Western pitch structure and the other's violated either key structure (in two conditions) or harmony (in one condition). We measured children's tendency to award the prize to the puppet whose song conformed to key and harmony rules. Our design was an improvement on previous studies for two reasons: first, the addition of videos, puppets, and prizes made the task more engaging for children compared to just listening and making judgments to the musical stimuli and, second, this procedure required many fewer trials than in previous studies, ensuring that children maintained attention throughout the experiment. Furthermore, we aimed to improve the generalizability of our results compared to previous studies by presenting a different sequence on each trial so that children's performance reflected general enculturation rather than specific learning of the particular experimental stimuli. Finally, we also administered tests of simple memory span as well as receptive language ability to examine whether these cognitive skills were associated with children's performance.

Method

Participants. We tested 72 4-year-olds (36 girls, 36 boys; M_{age} = 4.5 years, *SD* = 0.1 years) and 72 5-year-olds (36 girls, 36 boys; M_{age} = 5.5 years, *SD* = 0.1 years), with 12 girls and 12 boys of each age group assigned to one of three conditions. None of the children were enrolled in formal music lessons. An additional 22 children were tested but excluded from the final analysis for the following reasons: enrolled in formal music training (*n* = 13), diagnosed with a developmental disorder (*n* = 5), failed to complete all testing (*n* = 2), or experimenter error (*n* = 2).

Stimuli. ***Musical Sequences.*** We composed eight chord sequences, each consisting of five 4-note chords in root position, and eight 8-beat single-line melodies (each melody was two measures long in simple time) typical of Western musical structure. There were four versions of each chord sequence and each melody. The first was a *standard version* that followed the rules of Western harmony and always ended on the tonic note or chord. In the *atonal version*, each note or chord of the standard version was shifted up or down by a semitone, or left the same such that the sequence as a whole did not belong to any particular key, while it maintained the same chord types (for chord sequences), or the same up/down pitch contour as the standard version (for melodies). The *unexpected key version* replicated the standard version exactly except that the last note or chord ended one semitone higher than the tonic and thus went outside the key (a flat supertonic). The *unexpected harmony version* replicated the standard version exactly except that the last note or chord ended on the subdominant, which is an in-key but less expected ending harmonically than the tonic. The subdominant and tonic chords are both major chords, ensuring that the results would reflect whether children expected the tonic chord in particular rather than simply any major chord. The standard, unexpected key, and unexpected harmony versions were composed such that neither the tonic nor the subdominant chord (in the chord sequences) or note (in the melody sequences) occurred in each sequence until the final chord or note. This was done to ensure that judgments of how these sequences ended could not be based on the frequency of occurrence of particular notes or chords in each sequence; rather, judgments would reflect children's knowledge of the rules of Western key membership and harmony. Figure 1 shows the musical notation for all four versions of one example test chord sequence and one example test melody. One additional chord sequence and one additional melody were composed and used for practice trials. For these sequences, the deviant versions violated Western musical structure strongly by including dissonant chords (for chord sequences) or large jumps in pitch that also went outside the key (for melody sequences). Chord sequences were 6 seconds in length and melodies were 4 seconds in length. To ensure that our standard sequences reflected Western musical structure, we had a music theorist examine and confirm that they were properly composed. To ensure that enculturated Western listeners did indeed perceive the standard versions as sounding expected or correct, and deviant versions as sounding unexpected or incorrect, we first had adult listeners (recruited without regard to music training) perform a longer version of the task. Thirty-six adults (20 females, 16 males) between the ages of 18 and 46 years (M_{age} = 21.9 years, *SD* = 5.4 years) listened to one standard and one deviant version each of all eight chord sequences and all eight melodies, and judged which version sounded better. Adults selected the standard version significantly above the expected chance level of .5 across all deviant conditions (all ps < .01), confirming the appropriateness of our stimuli: chords/atonal, *M* = .92, *SD* = .16; chords/unexpected key, *M* = .98, *SD* = .08, chords/unexpected harmony, *M* = .80, *SD* = .32, melodies/atonal, *M* = .94, *SD* = .17, melodies/unexpected key, *M* = .89, *SD* = .23, melodies/unexpected harmony, *M* = .90, *SD* = .18.

Videos. Puppets were filmed pressing keys on a toy keyboard to the rhythm of the chord sequence or melody. Each trial consisted of a standard and a deviant version of a chord sequence or melody, and different puppets played each version. Each puppet pair (e.g., a cow and a pig) was associated with one particular chord sequence and one particular melody. Videos were then edited and paired with the previously created audio files using Adobe Premiere, and exported to .mp4 file formats. Because the audio files were added to the videos after recording, we were able to pair the same video clip with all four versions of its corresponding chord sequence or melody. This procedure enabled us to counterbalance the particular puppet in each pair that played the standard across children while keeping the videos constant. Videos lasted 9 seconds for chord sequences and 8 seconds for melodies, and all videos began with 2.5 seconds of silence and ended with silence.

Procedure. Each child sat at a small table in front of a 24-inch widescreen monitor and M-Audio Studiophile AV 40 speakers, which were both connected to a 3.4GHz iMac using iTunes to play all videos. The experiment was framed as a puppet concert, where children would give prizes to the puppets that played the best songs. On each trial, the child first watched videos of two puppets playing the piano: one played the standard version and the other played one of the three deviant versions. The experimenter then placed both of the puppets seen in the videos in front of the child and asked: “Who gets the prize?” The child placed a ribbon on whichever puppet he or she deemed the winner. Each individual child completed the chord and melody conditions (one practice trial and 4 test trials each) for one deviant type (atonal, unexpected key, or unexpected harmony).

Whether children heard chords or melodies first was counterbalanced across children. For each child, the standard came first for half of the trials and second for the remaining half, and the puppet that played the standard was placed in front of the child on the left for half of the trials and on the right for the other half. Each particular puppet appeared only once to each individual child so that judgments could not be based on the puppet's past reliability (i.e., whether the puppet previously played the standard or deviant sequence), and every trial began in a new key so that children could not base their judgments on the frequency of a particular set of absolute pitches.

Each child additionally completed a forward digit span test between the two blocks of trials as a measure of short-term memory, and the Peabody Picture Vocabulary Test – 4th Edition (PPVT-4; Dunn & Dunn, 2007) after both blocks as a measure of receptive language ability. Because there are no published norms on children's digit span scores below the age of 6, we used their raw scores. Children's PPVT-4 scores were standardized according to age. Parents completed a questionnaire on their child's demographics, musical exposure, extracurricular activities, and basic health. Each child received a book or toy and certificate as appreciation for participating.

Results and Discussion

The dependent measure was the proportion of trials on which children selected the puppet that played the standard version. Figure 2 shows the average for each age group (4-year-olds, 5-year-olds) for each song type (chords, melodies) and deviant condition (atonal, unexpected key, unexpected harmony). We first conducted a series of planned *t* tests comparing children's performance to chance (0.5). As these were planned analyses, we did not correct for the number of *t* tests performed. Four-year-olds performed at chance in every case: chords/atonal, $t(23) = 1.10$, $p = .29$; melodies/atonal, $t(23) = 1.23$, $p = .23$; chords/unexpected key, $t(23) = 1.30$, $p = .21$; melodies/unexpected key, $t(23) = 1.00$, $p = .33$; chords/unexpected harmony, $t(23) = .94$, $p = .36$; melodies/unexpected harmony, $t(23) = 1.34$, $p = .19$. By contrast, 5-year-olds selected the puppet that played the standard version significantly more often than predicted by chance in the atonal condition for both chords, $t(23) = 3.82$, $p < .01$, and melodies, $t(23) = 2.60$, $p = .02$, and in the unexpected key condition for both chords, $t(23) = 3.21$, $p < .01$, and melodies, $t(23) = 3.56$, $p < .01$, suggesting that these children had knowledge of key membership. Five-year-olds performed at chance, however, in the unexpected harmony condition for both chords, $t(23) = .85$, $p = .41$, and melodies, $t(23) = 1.57$, $p = .13$, suggesting that they are not yet able to demonstrate behavioral sensitivity to harmonic relationships within a given key.

To directly compare 4- and 5-year-olds' performance and to examine the possibility of sex differences, we conducted a 2×2×2×3 ANOVA with song type (chords, melodies) as the within-subjects factor and age group (4-year-olds, 5-year-olds), sex (girls, boys), and deviant condition (atonal, unexpected key, unexpected harmony) as between-subjects factors. There were significant main effects of age group, $F(1,132) = 5.00$, $p = .03$, and sex, $F(1,132) = 5.51$, $p = .02$; the main effect of condition approached significance, $F(2,132) = 2.60$, $p = .08$, as did the age group by condition interaction, $F(2,132) = 2.38$, $p = .10$, but no other effects were significant (all *p*s > .10). These results reflected the fact that 5-year-olds performed better than 4-year-olds, and that girls performed better than boys. Because the age group by condition interaction approached significance, we performed separate one-way ANOVAs for each condition with age group as a between-subjects factor on children's overall performance because we did not find any significant effects involving song type in the previous analysis. There was a significant effect of age group in the atonal condition, $F(1,46) = 5.23$, $p = .03$, and in the unexpected key condition, $F(1,46) = 4.25$, $p = .05$, but not in the unexpected harmony condition, $F(1,46) = .24$, $p = .63$. These results reinforce the previous analyses comparing children's performance to chance. In summary, 5-year-olds outperformed 4-year-olds in the conditions that tested for knowledge of key membership (atonal and unexpected key conditions), with 4-year-olds performing at chance and 5-year-olds significantly above chance. On the other hand, the two groups performed similarly in the condition that tested for knowledge of harmony (unexpected harmony condition), with both groups performing at chance.

We conducted several further analyses. First, we asked whether the tendency for girls to perform better than boys was a general cognitive effect or whether it was specific to our music task. We conducted *t* tests to compare girls' and boys' performance on the digit span task and the PPVT-4. Girls and boys did not differ on either the digit span task, $t(142) = .39$, $p = .70$, or on the PPVT-4, $t(142) = .31$, $p = .76$, suggesting that the girls' advantage was specific to the music task. It is possible that girls have more musical exposure than boys. Examination of the questionnaires completed by parents revealed that girls were more likely than boys to have taken baby or toddler music classes and/or dance classes (Mann-Whitney $U = 1184.5$, $p < .01$).

Next, we conducted correlational analyses to investigate whether the cognitive development in memory and language skills between 4 and 5 years of age might explain 5-year-olds' superior performance compared to 4-year-olds. To do this, we examined whether children's overall performance on our music task was correlated with their digit span and PPVT-4 scores. The results of these correlational analyses are reported in Table 1. Children's overall music performance averaged across song types was not correlated with their digit span, $r = .12$, $p = .17$, but the correlation between their music performance and their PPVT-4 scores approached significance, $r = .15$, $p = .08$. These results suggest that memory skills were not influencing children's performance on the music task, but that children's language skills might in part affect their musical perception performance. It is possible that children with more advanced language skills were better able to understand the task and thus performed better; alternatively, it is possible that receptive vocabulary acted as a estimate of overall intelligence and that more intelligent children tended to perform better on the music task.

In Experiment 1, we assessed young children's explicit judgments of unfamiliar sequences that did or did not violate Western key membership or harmony. Using this engaging and age-appropriate but conservative test, we found that 5-year-olds were sensitive to key membership but not harmony, and that 4-year-olds did not demonstrate any knowledge of Western pitch structure in their explicit judgments. In Experiment 2, we examined whether event-related potentials might reveal partial or preattentive musical knowledge in 4-year-olds.

Experiment 2

We recorded EEG while 4-year-olds watched a silent movie to keep them entertained, and listened to a subset of the stimuli from Experiment 1. We measured ERPs to the last note or chord of each sequence and compared the responses to standard, expected endings with responses to unexpected key or unexpected harmony endings. In particular, we examined whether children showed an ERAN or ERAN-like response, similar to what has been found in adults and older children. To our knowledge, this is the first ERP experiment in children that included both melody and chords conditions, and that tested musical syntactic knowledge using both unexpected key and unexpected harmony deviants.

Method

Participants. Forty-six 4-year-olds (24 girls, 22 boys; M_{age} = 4.5 years, SD = 0.1 years) participated. All but two of these children completed two blocks (one chords, one melodies) of the same deviant condition. An additional two children completed both blocks but were excluded from one of these blocks for excessive artifacts in their EEG data. The final sample included 12 girls and 10 boys in the chords/unexpected key condition, 11 girls and 11 boys in the melodies/unexpected key condition, 12 girls and 9 boys in the chords/unexpected harmony condition, and 12 girls and 11 boys in the melodies/unexpected harmony condition. Most children had previously participated in Experiment 1 (n = 30), but whenever possible, we presented them with different sequences than they had heard previously. An additional eight children were recruited to participate but excluded from both blocks of the final sample for the following reasons: unwilling to put or keep the EEG cap on (n = 2), excessive movement or artifacts in the EEG data (n = 5), enrolled in formal music training (n = 1).

Stimuli. We used a subset of the standard, unexpected key, and unexpected harmony versions of the same sequences from Experiment 1 (four chord sequences and four melodies), and transposed each to all 12 major keys. However, we sped up the tempo of these sequences such that each lasted 3.6 seconds in order to maximize the number of trials we could present in each 15-minute block.

Procedure. Children sat either next to their parent or on their parent's lap in a sound-attenuated room, facing a speaker and a monitor that were positioned approximately 1 meter away. An experimenter instructed children to be "as quiet as a mouse" and "as still as a statue" and silently reminded them of these instructions if they forgot during the experiment. Children watched a silent movie of their choice while the musical stimuli played from the speaker. Most children completed one block of chords and one block of melodies of the same deviant condition with a short break in between the blocks (see *Participants* section), and we counterbalanced the order of these blocks across children.

Each block included 120 trials of the standard and 120 trials of the deviant version of the same melody or chord sequence, transposed to all major keys and presented in a pseudo-random order such that no two consecutive trials could be presented in the same key. Stimuli were presented using E-prime version 1.2 software. After the experiment, children received a certificate and a book or toy as appreciation for participating.

EEG Data Recording and Analysis. We recorded EEG with a Geodesic Sensor net and Electrical Geodesics Inc. Netstation 4.3.1 software at 124 or 128 scalp locations (depending on the net size that fit the child's head). Online, EEG was recorded at a sampling rate of 1000 Hz with a Cz reference, and bandpass filtered between 0.1 and 400 Hz, keeping impedances below 50 kΩ. Offline, the data were filtered between 0.5 and 20 Hz, downsampled to 200 Hz, and then run through the artifact-blocking (AB) algorithm (see Fujioka, Mourad, He, & Trainor, 2011) using a threshold of ±100 μV to reduce movement-related artifacts. Electrodes were then digitally re-referenced to a common average, and the data were segmented into 900 ms epochs with a baseline starting 100 ms before the onset of the final chord (chord sequences) or note (melodies) of each trial. For each electrode site, standard and deviant trials were averaged separately relative to the 100 ms baseline. For analysis, eight groups of electrodes were formed, averaging together the channels in each group that corresponded to frontal, central, parietal, and occipital regions of the scalp for each hemisphere (see Figure 3). We then created a difference wave for each participant in each condition at each scalp region by subtracting the standard waveform from the deviant waveform.

Results and Discussion

Grand average standard and deviant waveforms in each condition are shown in Figure 4, and difference waves in Figure 5. Preliminary *t* tests comparing standard and deviant waves across time revealed an early component (deviants more positive than standards) in both the chords/unexpected key and chords/unexpected harmony conditions. In addition, a late positive component was identified in the chords/unexpected harmony condition. A late positive component also appeared to be present in the chords/unexpected key condition, but was not significant by *t* tests across time. These components were present in both the frontal and central regions and reversed polarity in the occipital regions (see Figure 6 for head maps of the grand average difference waves for the chords/unexpected key condition at 200 ms after the onset of the final chord, and for the chords/unexpected harmony condition at 240 ms and at 550 ms). No significant differences were observed for the melody conditions.

The peaks of the early and late components in the grand average at frontal and central sites identified in the preliminary analyses were used to specify times windows (+/- 50 ms around the peak of the grand average for the early component, +/- 125 ms around the peak of the grand average for the late component) in which the average amplitudes of the difference waves were calculated and used as the dependent measures in the following analyses. The average amplitudes at occipital regions were reverse-signed (such that negative average amplitudes were transformed to have a positive average amplitude and vice versa) so that the magnitude of the component across scalp regions could be analyzed. Parietal regions were not included as no significant components were present. No components could be identified in either the melodies/unexpected key condition or the melodies/unexpected harmony condition; thus, analyses in these conditions were conducted using the time windows of the corresponding chords condition of the same deviant type. Greenhouse-Geisser corrections to degrees of freedom were used whenever appropriate. For each analysis (early and late components for each condition), within-subjects factors were hemisphere (left, right) and region (frontal, central, occipital), and the between-subjects factor was sex (girls, boys).

Key Membership. In the chords/unexpected key condition, the time window of the early peak was 150 to 250 ms after the onset of the final chord. The ANOVA revealed no main effect of hemisphere [$F(1,20) = 1.78$, $p = .20$], region [$F(2,40) = 1.80$, $\varepsilon = .76$, $p_{adj} = .19$], or sex [$F(1,20) = .30$, $p = .59$], and no significant interactions involving any of these factors, suggesting that the size of the early component was similar across hemispheres, regions, and sex of the participants. Because we did not find any main effects or interactions in the overall ANOVA, we then conducted a *t* test on the average amplitude of the difference wave between 150 and 250 ms, averaged across the left and right frontal, central, and occipital regions and found that it was significantly different from zero, $t(21) = 4.31$, $p < .01$. The time window for the late component in the chords/unexpected key condition was between 335 and 585 ms. It did not differ according to hemisphere [$F(1,20) = 1.47$, $p = .24$], region [$F(2,40) = .36$, $\varepsilon = .72$, $p_{adj} = .64$], or sex [$F(1,20) = .94$, $p = .34$], and there were no significant interactions. However, in this case, the average amplitude also did not differ significantly from zero, $t(21) = .64$, $p = .53$.

Thus, in contrast to the ERAN that has been found in children as young as 5 years (e.g., Jentschke et al., 2008; Koelsch et al., 2003), we found an early positivity in frontal areas in younger children with an average age of 4.5 years. These results suggest that young children have some sensitivity to key membership at the level of implicit processing because in-key chords elicited a different pattern of brain activity than out-of-key chords at an early latency. However, the fact that their response was an immature bilateral positivity in frontal scalp sites rather than an adult-like right-lateralized frontal negativity further supports the idea that this component may reflect knowledge that cannot yet be expressed behaviorally.

Because we could not identify any components in the melodies/unexpected key condition, we used the same time windows as in the chords/unexpected key condition for the analyses (early: 150 to 250 ms; late: 335 to 585 ms). There were no significant main effects or interactions for either the early or late component, and neither of the average difference wave amplitudes differed significantly from zero (both *p*s > .30). Thus, we did not find any significant components in the difference waves of the melodies/unexpected key condition. Because components that are elicited by expected compared to unexpected notes in melodies are quite small even in adults (e.g., Koelsch & Jentschke, 2010), it is perhaps unsurprising that we failed to identify any such components in young children. Chords contain rich harmonic information because of the simultaneous combination of notes, whereas melodies contain less information and therefore fewer cues to key and harmony.

Harmony. In the chords/unexpected harmony condition, the early component was measured as the average amplitude of the difference wave between 190 and 290 ms. The ANOVA revealed no main effect of hemisphere [$F(1,19) = .00$, $p = .95$], region [$F(2,38) = .64$, $\varepsilon = .77$, $p_{adj} = .50$], or sex [$F(1,19) = .70$, $p = .42$], and no significant interactions, but the average amplitude of the component across hemispheres and regions differed significantly from zero, $t(20) = 2.95$, $p < .01$. The late component was measured between 425 and 675 ms. Again there was also no main effect of hemisphere [$F(1,19) = .22$, $p = .65$], region [$F(2,38) = 1.51$, $\varepsilon = .71$, $p_{adj} = .24$], or sex [$F(1,19) = .62$, $p = .44$], and no significant interactions involving these factors. The *t* test comparing the average amplitude of the difference wave between 425 and 675 ms across hemispheres and regions to zero approached significance, $t(20) = 1.92$, $p = .07$. Thus, similar to in the chords/unexpected key condition, an early positivity was also elicited in the chords/unexpected harmony condition, as well as a trend for a late component. These results are perhaps surprising in light of the behavioral results of Experiment 1, in which even 5-year-olds did not demonstrate knowledge of within-key harmonic expectations. The ERP findings suggest that children begin accumulating knowledge pitch structure long before that knowledge is sophisticated enough to be expressed behaviorally.

The same time windows identified in the chords/unexpected harmony condition were used in the melodies/unexpected harmony condition. There were no significant main effects of hemisphere, region, or sex for either the early component (190 to 290 ms) or the late component (425 to 675 ms), and no significant interactions. Neither component differed from zero (both *p*s > .40); thus, we could not identify any significant components in the melodies/unexpected harmony condition. As this condition contained only weak harmonic violations to simple melodies, the most subtle manipulation of the experiment, this result is perhaps not surprising.

General Discussion

Our first goal was to examine the development of children's explicit evaluative judgments of sequences that did or did not conform to Western pitch structure. Our task was engaging and maintained children's attention, but it was also conservative because each trial included a different unfamiliar sequence, ensuring that children's responses reflected their abstract knowledge of key membership and harmony rather than specific knowledge of the particular sequences used in the experiment, as was the case in previous studies (e.g., Corrigall & Trainor, 2009, 2010; Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Trainor & Trehub, 1994; Trehub et al., 1986). We found that 5-year-olds were sensitive to key membership as they chose to award prize ribbons to puppets that played standard Western sequences significantly more often than puppets that played atonal sequences or sequences that ended in an unexpected key. However, whether a sequence ended in an unexpected or expected harmony did not affect 5-year-olds' awarding of prize ribbons, which suggests that they were not yet sensitivity to harmony. By contrast, 4-year-olds did not demonstrate any knowledge of Western pitch structure through explicit judgments, as they awarded prize ribbons equally to puppets that played standard compared to deviant sequences. These results suggest that children's knowledge of key membership is sophisticated enough to be expressed through evaluative judgments by approximately 5 years of age.

These findings fit with previous research that suggests that children acquire sensitivity to key membership before harmony (e.g., Corrigall & Trainor, 2009, 2010; Trainor & Trehub, 1994), and extend it in two ways. First, there were no differences in performance for chordal compared to melodic sequences, which suggests that there is a similar developmental trajectory for sensitivity to Western pitch structure in these two contexts. Second, 5-year-olds were sensitive to key membership in both the atonal and the unexpected key conditions whereas 4-year-olds were not. These results suggest that once children can demonstrate knowledge of key membership through explicit judgments, their knowledge can generalize across different contexts of key membership violation. In other words, 5-year-olds appear to be just as good at identifying one wrong chord or note in a Western sequence as they are at recognizing that an entire passage does not conform to Western key membership rules. Together with previous research, the findings suggest that children have a fairly stable representation of key membership by approximately 5 years of age (e.g., Corrigall & Trainor, 2009, 2010; Jentschke et al., 2008; Koelsch et al., 2003; Trainor & Trehub, 1994; Trehub et al., 1986), but that a stable representation of harmony may not be in place until 6 or 7 years of age (e.g., Cuddy & Badertscher, 1987; Schellenberg et al., 2005; Trainor & Trehub, 1994), or even later (Costa-Giomi, 2003; Krumhansl & Keil, 1982).

Sensitivity to key membership and harmony likely arises through the accumulation of passive exposure to Western music. Children may then come to internalize the statistical regularities of the note and chord patterns that form the basis of key membership and harmony rules. However, general cognitive development might also contribute to the acquisition of musical knowledge itself, as well as to children's ability to express this knowledge. Our failure to find a correlation between performance on the music task and short-term memory in Experiment 1 suggests that children's performance on the music task was not driven by their memory skills. The near-significant correlation between performance on the music task and receptive vocabulary, however, suggests that children's understanding of the task or even general intelligence may contribute to their music task performance. On the other hand, we also obtained suggestive evidence that experience with music was a better predictor of musical enculturation than general cognitive skills: while girls and boys performed equally well on the general cognitive tasks, girls tended to outperform boys on the music tasks. Because girls were also more likely to have participated in early music or dance classes, our results point to the importance of everyday experience in acquiring knowledge of key membership and harmony. Furthermore, there is evidence that formal music training accelerates the development of sensitivity to Western pitch structure in both infants and children (Corrigall & Trainor, 2009; Gerry et al., 2012; Trainor et al., 2012), presumably because children in music lessons acquire more exposure to music than children not in lessons. Although these observations and correlations are suggestive of the role that experience plays in musical enculturation, further research is needed to confirm its importance. One issue that arises is the difficulty in quantifying how much music children are exposed to. It may be easy to estimate how often one deliberately listens to music on CDs, portable music players, and the radio, but music is also present in shopping malls, in schools and daycares, on television, and in movies, etc. A challenge for future research will be to accurately quantify children's amount of exposure to Western music and to examine whether this experience best explains individual differences in their sensitivity to key membership and harmony.

Our second goal was to examine implicit or pre-conscious knowledge of key membership and harmony in 4-year-old children who could not yet demonstrate this knowledge behaviorally. Children showed a positive ERP component in frontal and central regions between approximately 150 and 250 ms after the onset of the final chord in the chords/unexpected key condition, and between 190 and 290 ms as well as between 425 and 675 ms after the onset of the final chord in the chords/unexpected harmony condition. These results stand in contrast to previous studies with older children and adults that have found negative components (i.e., the ERAN and the N5) in response to similar stimuli (e.g., Koelsch et al., 2000; Koelsch et al., 2001; see Koelsch, 2009 for a review). However, the positive components found in the current study were of a similar latency and were present in the same scalp regions as in previous ERAN studies with older children (e.g., Jentschke et al., 2008; Koelsch et al., 2003). Other auditory ERP components that appear as frontal negativities in adults also manifest as positivities in young children and infants (e.g., He, Hotson, & Trainor, 2009; Tew, Fujioka, He, & Trainor, 2009; Trainor et al., 2003). We therefore suggest that the positive components that we obtained represent an immature ERAN-type response to a musical syntactic violation that emerges in development before behavioral sensitivity to these violations.

It is possible that our behavioral task in Experiment 1 was too difficult or not engaging enough to reveal 4-year-olds' knowledge of key membership and harmony; however, there are several reasons why this is unlikely to be the case. First, we used the same musical stimuli in Experiments 1 and 2, ensuring that the same musical expectations should have been elicited across experiments. Second, we observed that 4-year-olds were very attentive in the behavioral music task. Third, short-term memory was not correlated with performance on the music task in Experiment 1, which suggests that the task was not overly demanding on memory capacity. Finally, because the early positive ERP components were short in latency and elicited under passive listening conditions, it suggests that they were automatic, implicit responses to violations of key membership and harmony. Thus, 4-year-olds' representation of Western pitch structure may not yet be strong enough to be expressed explicitly. However, the presence of the significant immature frontally positive ERP response suggests that at least a primitive representation of key membership and harmonic structure exists at age four.

In sum, we found that by 5 years, children have a fairly robust and sophisticated understanding of key membership because they were able to make explicit judgments about the appropriateness of stimuli that did or did not violate Western key membership rules. However, 5-year-olds could not make these same judgments for stimuli that did or did not violate Western harmony rules, suggesting that harmony perception takes longer to develop. By contrast, while 4-year-olds did not demonstrate behavioral knowledge of key membership or harmony, their brain responses to chord sequences suggested that they have an immature pre-conscious cortical representation of both key membership and harmony. Overall, our findings suggest that there is a long developmental trajectory for enculturation to Western pitch structure, and that children may have implicit or pre-conscious knowledge of this structure long before they can express their knowledge behaviorally. Future research should pinpoint the youngest age at which sensitivity to key membership and harmony can be observed in order to better understand the development and emergence of enculturation to musical pitch.

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Table 1.

Correlational Analyses in Experiment 1

Variable	1.	2.	3.	4.
1. Age	-	.15†	.44**	-.11
2. Music performance		-	.12	.15†
3. Digit span			-	.32**
4. PPVT-4				-

† $p < .10$ * $p < .05$ ** $p < .01$

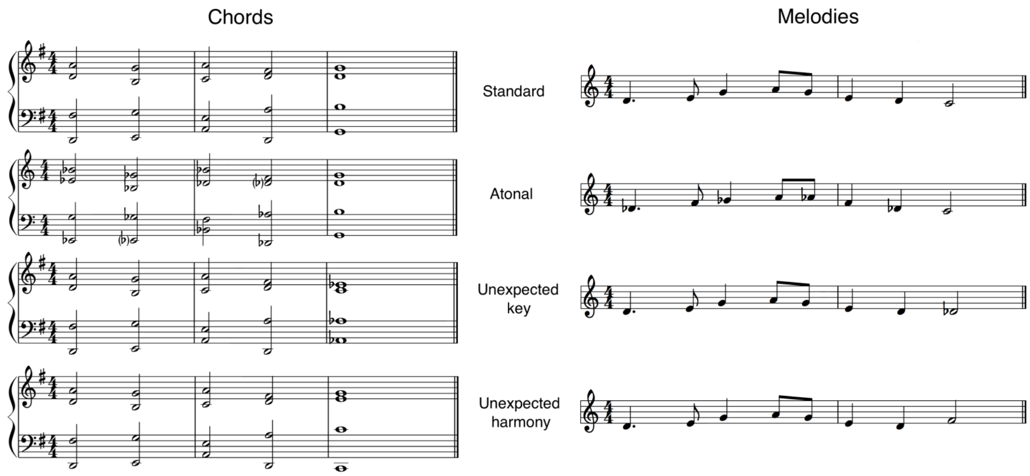

Figure 1. Musical notation for all four versions (standard, atonal, unexpected key, unexpected harmony) of one example chord sequence and one example melody.

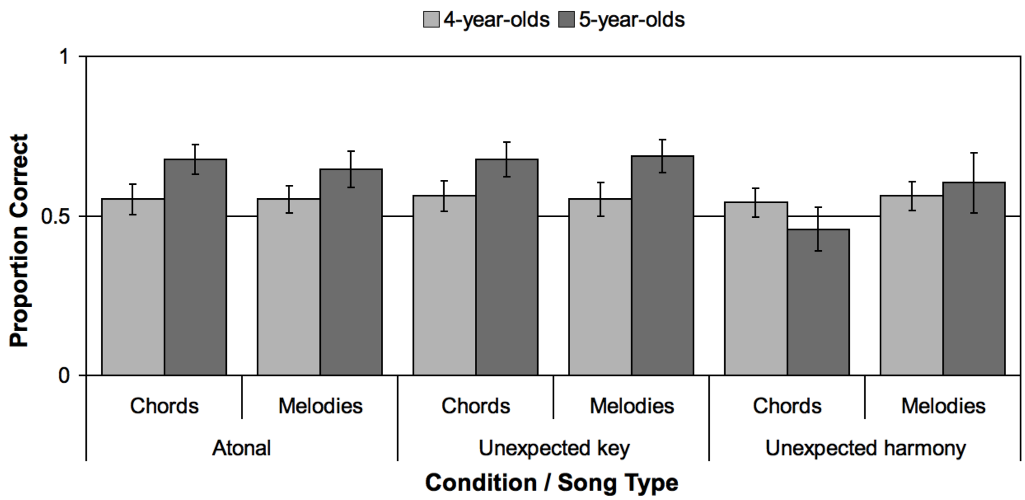

Figure 2. Behavioral results from Experiment 1. The proportion of trials that 4- and 5-year-old children chose the version that conformed to Western musical structure is shown for each condition. Error bars represent standard error.

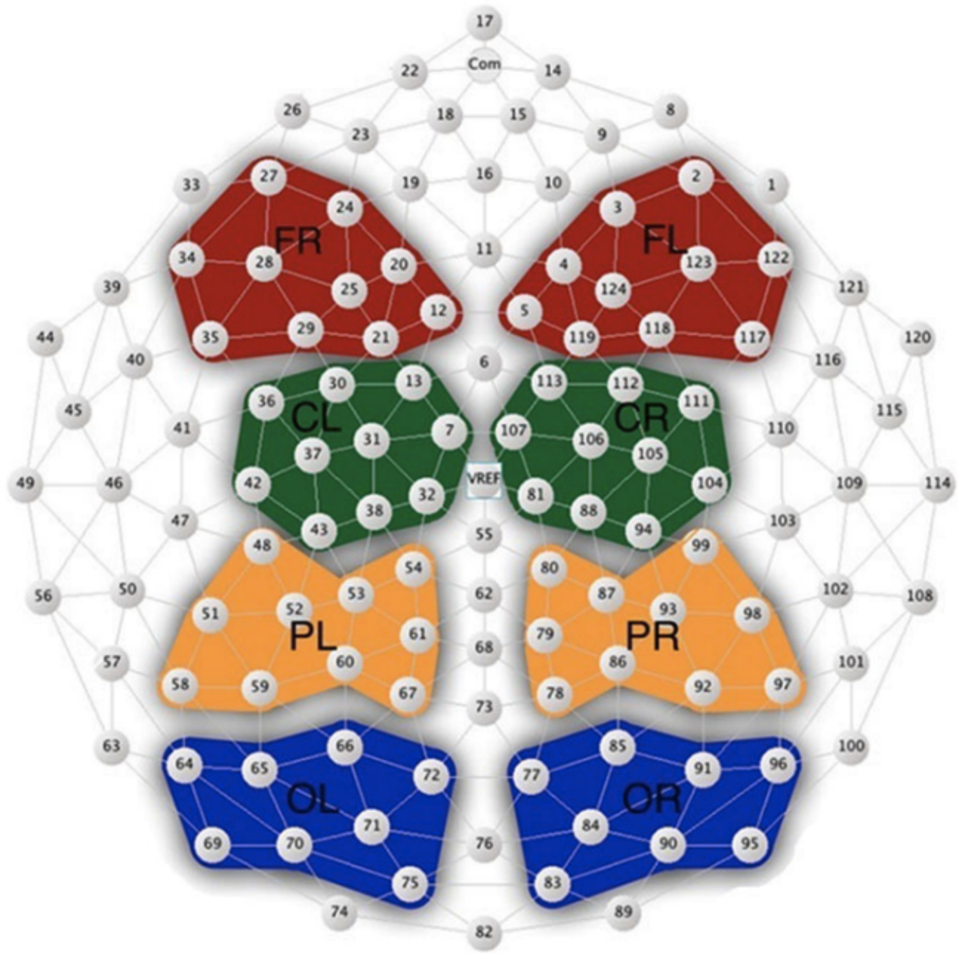

Figure 3. Electrode groupings used in the analyses of Experiment 2 (FL = frontal left, FR = frontal right, CL = central left, CR = central right, PL = parietal left, PR = parietal right, OL = occipital left, OR = occipital right). Each region included between 8 and 10 electrode sites.

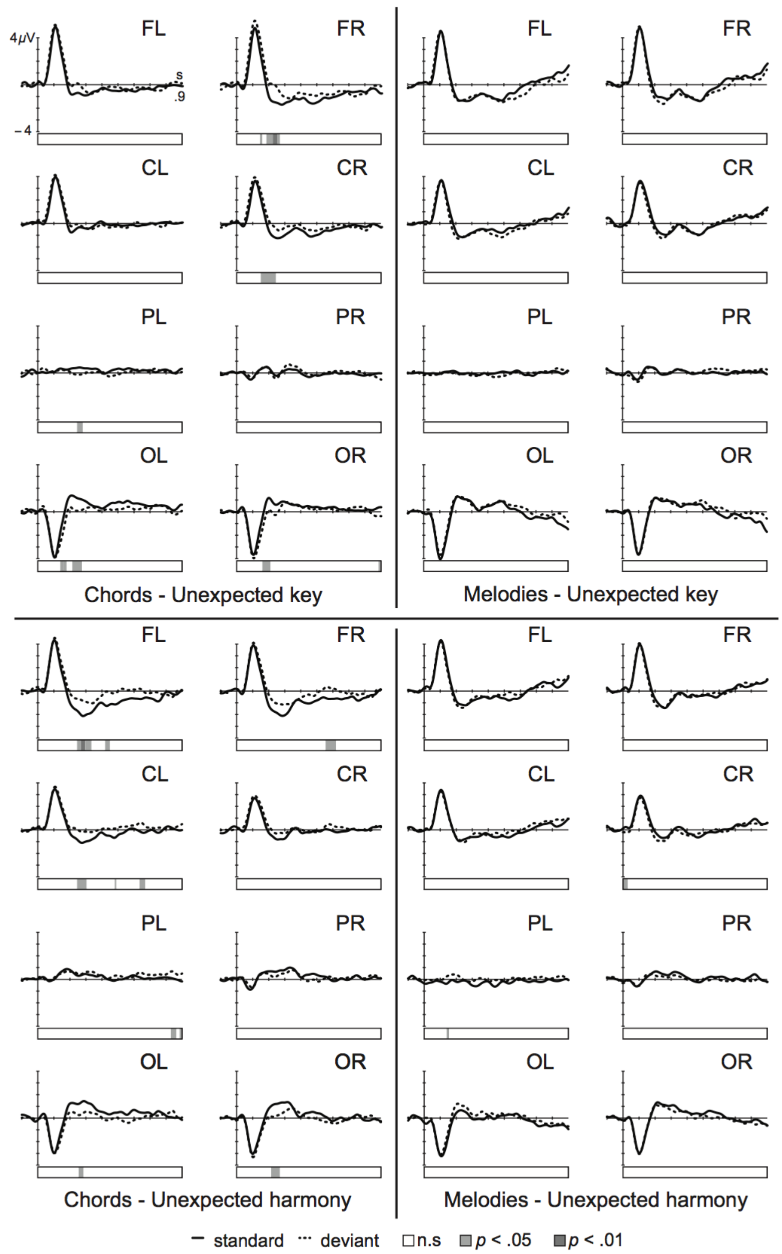

Figure 4. Grand average waveforms of responses to standards (black lines) and deviants (dotted lines) in each condition and in each region from Experiment 2. Boxes underneath each waveform indicate the significance level of *t* tests conducted on the difference between standard and deviant waves at each time point. The y-axis marks the onset of the last note or chord in each sequence.

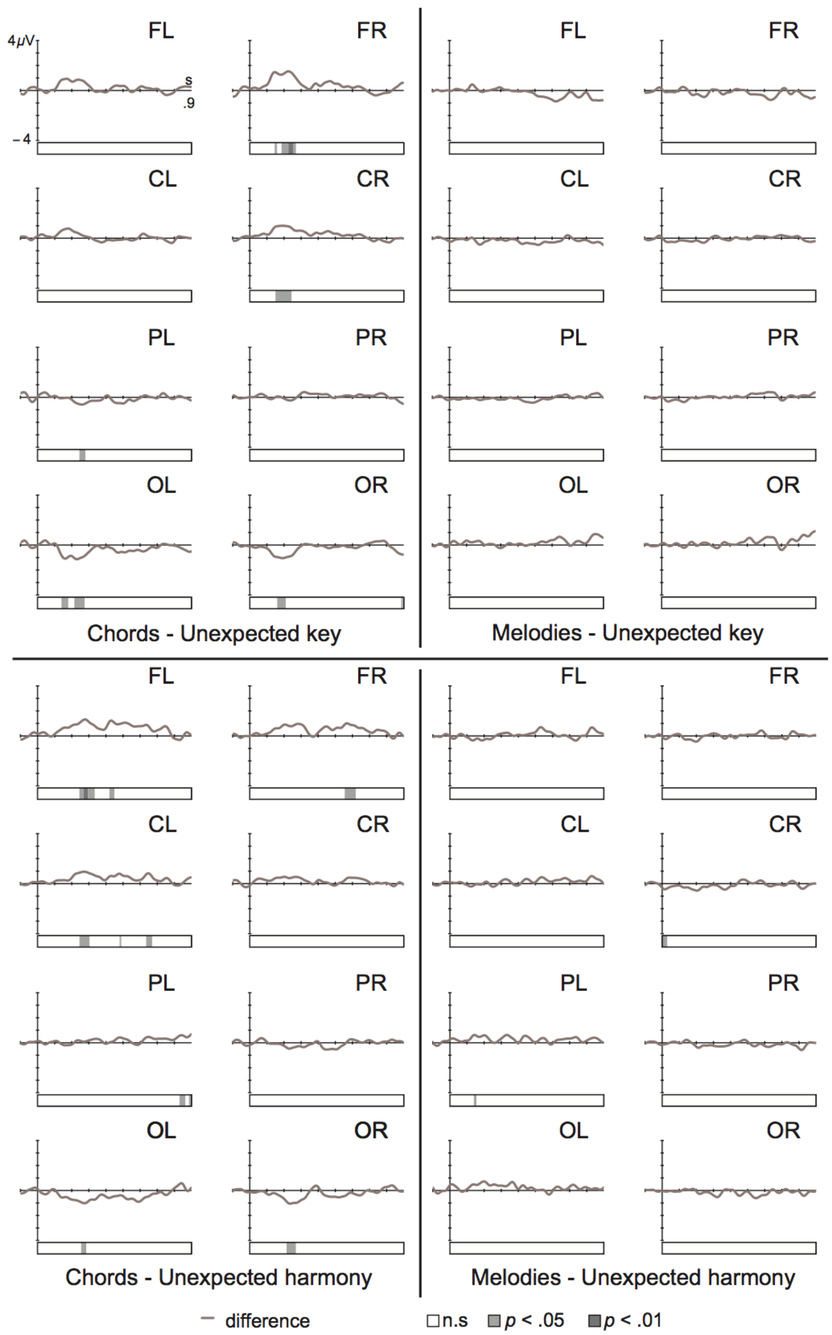

Figure 5. Averaged difference waves (deviant – standard; grey lines) in each condition and in each region. Boxes underneath each waveform indicate the significance level of *t* tests comparing difference waves to zero. The y-axis marks the onset of the last note or chord in each sequence.

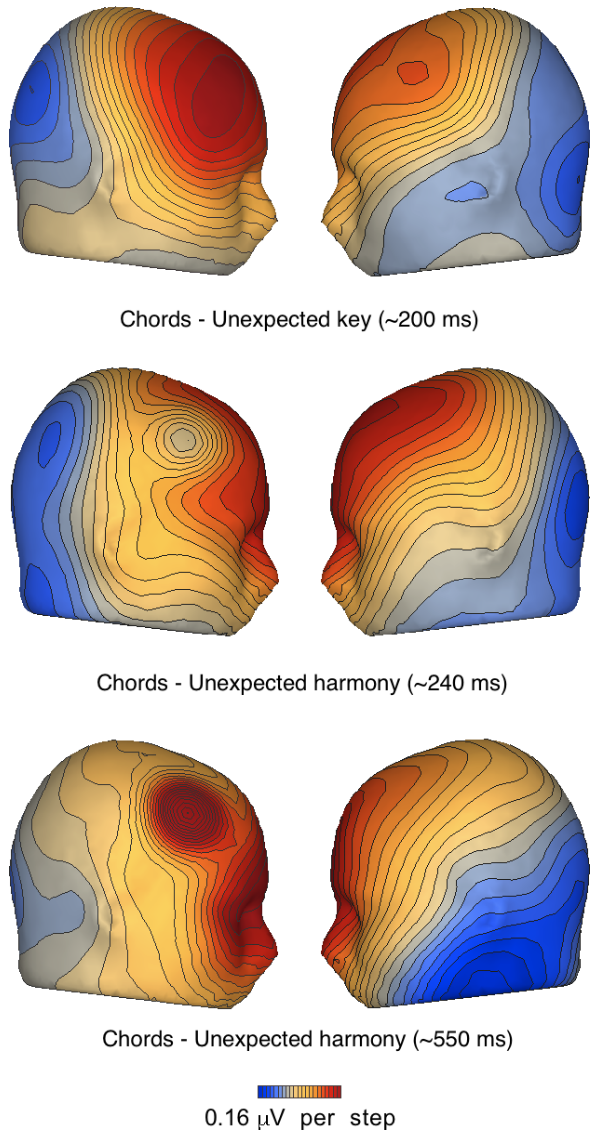

Figure 6. Topographies of the difference wave in the chords/unexpected key condition for the early component (at approximately 200 ms after the onset of the final chord), and the chords/unexpected harmony condition for the early component (at approximately 240 m ms) and the late component (at approximately 550 ms). The red end of the scale indicates a positive voltage while the blue end of the scale indicates a negative voltage.

CHAPTER 3: Musical enculturation in preschool children: Acquisition of key and harmonic knowledge

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Preface

The previous chapter provided a comprehensive and conservative test of young children's sensitivity to key membership and harmony in unfamiliar melodic and chordal sequences. At the same time, the results of Experiment 2 of Chapter 2 suggested that young children have implicit knowledge of musical pitch structure even though they are not yet able to express that knowledge through explicit behavioural judgments. These results imply that the developmental trajectory of enculturation to musical pitch structure is graded, beginning with implicit sensitivity and ending with full, abstract, explicit knowledge that can be expressed behaviourally and that can be applied to novel unfamiliar but typically-structured Western sequences. However, these findings beg the question of whether children possess partial explicit knowledge of key and harmony structure that can be behaviourally expressed in particular situations but not others.

The study reported in Chapter 3 tested whether children of a similar age to those tested in Chapter 2 could demonstrate knowledge of key membership and harmony in a familiar song (specifically, *Twinkle Twinkle Little Star*). Furthermore, children's knowledge was tested in three different contexts: 1) within the melody alone, 2) within the melody with full chordal accompaniment, and 3) within only the harmonic progression that typically accompanies the melody. This chapter demonstrates that children as young as 4 years old can demonstrate behavioural sensitivity to both key membership and harmony in the particular context when they are familiar with the musical stimulus. Furthermore, the results suggest that developmental differences in sensitivity emerge in the contexts where children are less familiar with the music, such as when the melody is removed from the chordal accompaniment. These findings support the hypothesis that the acquisition of enculturation to musical pitch follows a graded developmental path such that partial knowledge precedes full, abstract knowledge.

Abstract

Even adults without formal music training have implicit musical knowledge that they have acquired through day-to-day exposure to the music of their culture. Two of the more sophisticated musical abilities to develop in childhood are knowledge of key membership (which notes belong in a key) and harmony (chords and chord progressions). Previous research suggests sensitivity to key membership by 4 or 5 years, but provides no behavioral evidence of harmony perception until 6 or 7. Thus, we examined knowledge of key membership and harmony in 4- and 5-year-old children using a simple task and a familiar song. In line with previous research, we found that even the youngest children had acquired key membership. Furthermore, even 4-year-olds demonstrated some knowledge of Western harmony, which continued to develop between 4 and 5 years of age. In sum, our results indicate that harmony perception begins to develop earlier than has been previously suggested.

Introduction

As music is a form of communication and expression that is both unique to humans and universal across human cultures, musical acquisition is a significant component of normal development. As with language, it takes many years to acquire full musical receptive and productive competence. Similarly, music perception and production become specialized for the structure of the music in the environment even without formal instruction in, or explicit knowledge of, that structure. The process by which children acquire this knowledge is referred to as musical enculturation because it requires experience with the particular musical system of a given culture. In this paper, we examine the acquisition of knowledge about key membership and harmonic syntax in preschool children who are naturally exposed to Western music in everyday life, but who have not received formal music instruction.

The most common scale (or key type) in Western music is the major scale (or key), a seven-note subset of the chromatic scale, an equal division of the octave into 12 intervals called semitones. Acquisition of key membership is manifested as knowledge of whether or not a note belongs to the seven notes of the key in which a piece is written. The unequal spacing of the tones in the major scale (2, 2, 1, 2, 2, 2, 1 semitones) allows each note to take on a different function, and chords based on each note have different meanings. For example, the tonic chord, based on the first note of the scale, is the most stable, and the dominant, based on the fifth note, is the next most stable. The dominant-to-tonic progression is very common at the end of musical phrases, and creates a sense of expectancy: if the harmonies implied by these progressions are not realized, the "wrong" chord may sound surprising or even unpleasant (Huron, 2006; Meyer, 1956). Acquisition of harmonic knowledge includes knowledge about the probabilities by which different chords follow each other, and the hierarchy of stability engendered by the different chords. Even adults with no music training have implicit knowledge of this tonal hierarchy (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982), suggesting that it develops in childhood through mere exposure to Western music.

Research suggests that 8-month-old infants are not yet sensitive to key membership, but that sensitivity develops between infancy and 4 or 5 years of age. Trainor and Trehub (1994) found that 5-year-olds', 7-year-olds', and adults' detection of a wrong note was facilitated when the changed note went outside the key. However, infants detected in-key and out-of key changes equally well (Trainor & Trehub, 1992). The acquisition of key membership knowledge also appears to enhance processing of tonal music. Trehub, Cohen, Thorpe, and Morrongiello (1986) found that 4- and 5-year-olds could only detect a change in a tonal melody; in contrast, infants could also detect a change in an atonal melody.

Harmony perception appears to be one of the last musical skills to develop (e.g., Costa-Giomi, 2003). However, using an implicit task, Schellenberg, Bigand, Poulin-Charronnat, Garnier, and Stevens (2005) showed that 6- to 11-year-olds have some sensitivity to harmony. Children were primed with chord progressions, and made an unrelated, speeded judgment about the last chord (e.g., whether it was a piano or a trumpet tone). All children responded faster to the last chord when it followed Western harmony rules than when it did not, suggesting that even 6-year-olds have implicit knowledge of realized Western harmonic progressions. Furthermore, studies examining children's brain responses to harmonically appropriate and inappropriate chords in a musical context suggest that two event-related potential (ERP) components that are elicited by harmonic violations in adults, the early right anterior negativity (ERAN) and the N5, can also be elicited in children as young as 5 years old (Koelsch et al., 2003; Jentschke, Koelsch, Sallat, & Friederici, 2008). However, whereas both the ERAN and the N5 were elicited even to weak harmonic violations in adults (Koelsch et al., 2001), Koelsch et al. (2003) found that these components were only elicited to strong harmonic violations in children. These results suggest that implicit knowledge of Western harmonic structure is emerging in the preschool and early school years, and continuing to develop throughout childhood.

Harmonic structure affects melodic structure in Western music in that the different notes of a melody imply particular harmonies, and these harmonic implications color how a melody is perceived, even when the melody is presented without chordal accompaniment. Adults are sensitive to implied harmony in that they are faster to detect a note change in a melody if the change goes to a within-key note that is not in the implied chord expected at that point (i.e., the note sounds wrong or jarring as it doesn't fit the implied harmony) in comparison to another within-key note that is in the implied chord at that point (Trainor & Trehub, 1994). Seven-year-olds but not 5-year-olds appear to be like adults in their sensitivity to implied harmony (Trainor & Trehub, 1994). Similar results have been found using the probe-tone paradigm in which a musical context is given followed by a probe tone, which can be out-of-key, or consist of one of the seven notes in the context key. Krumhansl and Keil (1982) found that 6- and 7-year-olds preferred in-key notes to out-of-key notes, but they did not differentiate between different kinds of in-key notes, thereby not showing sensitivity to implied harmony. However, 8- to 11-year-olds additionally preferred notes that belonged to the tonic triad over notes that did not. Later probe-tone studies found that children as young as 6 years old could show sensitivity to the full tonal hierarchy if the task was simplified (Cuddy & Badertscher, 1987; Speer & Meeks, 1985). In sum, this research has provided evidence that children as young as 6 years are sensitive to harmonic structure.

Taken together, the available evidence suggests that children are sensitive to key membership at 4 or 5 years (e.g., Trainor & Trehub, 1994; Trehub et al., 1986), perhaps younger, but little is known about their harmonic sensitivity before 6 years of age (e.g., Cuddy & Badertscher, 1987; Schellenberg et al., 2005; Speer & Meeks, 1985; Trainor & Trehub, 1994). Thus, our goal was to examine the developmental acquisition of knowledge of key membership and harmony in younger children between 4 and 5 years of age. We expected that both age groups would show sensitivity to key membership, but that 5-year-olds would show greater sensitivity to harmonic violations than 4-year-olds.

Method

Participants

Twenty-seven 4-year-olds (20 girls, 7 boys; *M* = 4.0 years; *SD* = 0.3 years) and 25 5-year-olds (17 girls, 8 boys; *M* = 5.0 years; *SD* = 0.3 years) were tested individually at home, at school, or in a psychology laboratory. An additional four children were tested but excluded for failing to complete the task. Most children came from upper-middle-class families, and none had participated in formal music training.

Design

The task was designed to assess children's perception of key membership and harmony using a simple task and a familiar song (i.e., the first line of *Twinkle Twinkle Little Star*). Children received a sticker book and stickers for participating. In each condition, we asked children to use handheld happy and sad face signs to judge whether a frog puppet played each excerpt (or each trial) correctly or incorrectly, or whether it sounded good or bad (see the descriptions of each condition below). All stimuli were presented in a synthesized piano timbre from GarageBand over portable speakers connected to a computer. In each of three conditions, children were first presented with example and practice trials. Half of the 12 test trials were presented in the standard form in the key of D major, and half ended on one of three types of deviants: (1) out-of-key, (2) in key, but out-of-harmony, and (3) in key and within-harmony. Figures 1A-C show the full set of stimuli in each condition. We created two pseudorandom orders for each condition such that there were no more than three consecutive standard or three consecutive deviant trials. The three conditions were administered as part of a larger study, which included various nonmusical tasks that are not reported here. The three conditions were always presented in the same order, listed below, although there were intervening tasks between each of them. The three conditions were:

1. Melody Alone (Figure 1A). Only the melody was presented and the deviants occurred on the final note. In this condition, out-of-key deviants ended on the note D#, which does not belong to the key of D major. Out-of-harmony deviants ended on C#, a note that belongs to the key of D major but that does not belong to the tonic chord (D, F#, A), which is strongly implied at the end of the sequence. Within-harmony deviants ended on F#, which belongs to the tonic chord but nevertheless deviates from the standard ending (the note D). Children judged whether each trial ended correctly or incorrectly. This condition was administered to ensure that children were familiar with the song and performance was expected to be high.
2. Melody Accompanied by Chords (Figure 1B). Both the melody and the chords were presented, and the deviants occurred on the final chord (the melody was not changed). In this condition, out-of-key deviants ended on

a D minor chord, which contains one note (F natural) that does not belong to the key of D major, and is one step away from D Major in key space, according to Krumhansl and Kessler's (1982) spatial representation of all 24 major and minor keys. Out-of-harmony deviants ended on a G major chord, which contains notes that all belong to the key of D major but violate the strong expectation of a dominant-to-tonic chord progression at the end of the sequence. Within-harmony deviants simply ended on the same D major chord in inversion instead of in root position. Thus, our deviants were constructed such that physical deviance from the standard ending chord was pitted against the degree of musical violation: out-of-key deviants only slightly differed physically from the standard ending chord (i.e., one semitone in one note), whereas out-of-harmony and within-harmony deviants differed physically from the standard ending by a greater degree (see Figure 1). Therefore, if children based their judgments on the degree of physical deviance from the standard ending, they should actually be worst at detecting out-of-key deviants. However, if children based their judgments on the degree of key and harmony violation as we predicted, the opposite pattern should be observed. Thus, our stimuli were designed to be a strong test of our prediction that children's judgments would be based on degree of musical violation rather than degree of physical deviance. Because the melody was present, the song sounded familiar and we therefore asked children to judge whether each trial ended correctly or incorrectly.

3. Chords Alone (Figure 1C). Only the last five chords of the song clip were presented. The very same deviants occurred on the final chord as in the Melody Accompanied by Chords condition. Because the melody was absent, the music sounded unfamiliar. Therefore, we asked children to judge whether each trial sounded good or bad rather than judge whether each trial ended correctly or incorrectly.

We then calculated the mean proportion of trials judged as "right" (in the Melody Alone and Melody Accompanied by Chords conditions) or "good" (in the Chords Alone condition).

Results

Each condition was analyzed separately. A Greenhouse-Geisser correction for degrees of freedom was used whenever the sphericity assumption was violated. For each, an initial omnibus ANOVA was conducted with Age Group (4-year-olds, 5-year-olds) as the between-subjects factor and Trial Type (standard, out-of-key, out-of-harmony, within-harmony) as the within-subjects factor. For the Melody Alone condition (see Figure 2), the only significant effect was that of Trial Type, $F(3, 150) = 112.51$, $\varepsilon = 0.87$, $p_{adj} < .001$. We then conducted three ANOVAs comparing standard trials to each of the three types of deviant trials, which revealed significant differences between standard trials and each of the deviant trials (all ps < .01). This suggests that all children were familiar with the melody and could detect any type of change to it. Finally, we compared the three types of deviant trials to each other. The lack of a significant effect indicates that children detected each type of change equally well.

For the Melody Accompanied by Chords condition (Figure 3), the omnibus ANOVA revealed only a significant effect of Trial Type, $F(3, 150) = 45.57$, $\varepsilon = 0.77$, $p_{adj} < .001$. Standard trials differed significantly from each of the deviant trials (all *p*s < .05), suggesting that all children were sensitive to both key membership and harmony in a familiar context. Finally, comparing the three types of change trials to each other revealed that out-of-key and out-of-harmony trials did not differ significantly from each other ($p > .2$), but both of these differed from within-harmony trials (both *p*s < .01). Thus, children found out-of-key and out-of-harmony changes easier to detect than within-harmony changes.

For the Chords Alone condition (Figure 4) the omnibus ANOVA revealed a significant effect of Trial Type, $F(3, 150) = 46.58$, $\varepsilon = 0.95$, $p_{adj} < .001$, and an interaction between Age Group and Trial Type, $F(3, 150) = 3.15$, $\varepsilon = 0.95$, $p_{adj} < .05$. Because we found an effect involving Age Group, we kept it as a between-subjects factor in the next analyses comparing standard trials to each of the three types of deviant trials. These analyses revealed significant differences between standard trials and each of the deviant trials (all *p*s < .01). The only effect involving Age Group was a significant interaction in the analysis comparing standard and out-of-harmony trials ($p < .05$). To follow up, we examined the effect of Age Group on standard and out-of-harmony trials separately, and found a significant effect on out-of-harmony trials only, $t(50) = 2.03$, $p < .05$. Figure 4 shows that 5-year-olds outperformed 4-year-olds on these trials. Finally, we analyzed performance on the three types of change trials in 4- and 5-year-olds separately. In 4-year-olds, out-of-key trials differed significantly from both out-of-harmony and within-harmony trials (both *p*s < .01), but these did not differ significantly from each other ($p > .20$). This suggests that 4-year-olds found out-of-harmony and within-harmony changes more difficult to detect than out-of-key changes. In 5-year-olds, out-of-key and out-of-harmony trials did not differ ($p > .05$), but both of these differed from within-harmony trials (both *p*s < .01). These results suggest that 5-year-olds, but not 4-year-olds, show an adult-like pattern.

Discussion

Previous research demonstrated knowledge of key membership by 4 to 5 years of age (Trainor & Trehub, 1994; Trehub et al., 1986), but no previous studies had examined sensitivity to realized harmonic chord progressions in children younger than 6 years, and one study failed to find evidence of harmonic sensitivity to implied harmonies in 5-year-olds (Trainor & Trehub, 1994). We tested 4- and 5-year-olds with an easier task than had been used in previous research and found evidence of key membership knowledge and harmony perception even in our youngest participants who, at 4 years of age, were at least 2 years younger than the youngest age at which harmony perception had been demonstrated behaviorally (Cuddy & Badertscher, 1987; Schellenberg et al., 2005; Speer & Meeks, 1985). These results fit with electrophysiological evidence suggesting some harmonic knowledge in 5-year-olds (Jentschke et al., 2008; Koelsch et al., 2003).

Children of both age groups detected all types of deviant notes at near ceiling levels when only the melody was presented, suggesting that all children were very familiar with *Twinkle Twinkle Little Star*. Furthermore, children of both age groups easily detected out-of-key chord changes in the two conditions involving chords. Interestingly, both 4- and 5-year-olds easily detected out-of-harmony deviants when the song sounded familiar (i.e., when presented with both the melody and the chords), but 5-year-olds outperformed 4-year-olds at detecting these deviants when the song sounded unfamiliar (i.e., when presented with only the chords). Furthermore, while 4-year-olds were better at detecting out-of-key than in-key deviants, 5-year-olds were also better at detecting out-of-harmony than within-harmony deviants. These results suggest that 5-year-olds display a more adult-like pattern than 4-year-olds, and have a greater sensitivity to harmony. Finally, our results showed that even young children can detect within-harmony changes at above chance levels. However, detection of these subtle changes is not as good as detection of either out-of-key or out-of-harmony changes. In sum, the results indicate that 4- and 5-year-old children differ most in sensitivity to harmony.

Our results converge with previous findings suggesting that children develop sensitivity to key membership relatively early (e.g., Trainor & Trehub, 1994; Trehub et al., 1986), and that harmony perception develops later (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Schellenberg et al., 2005; Speer & Meeks, 1985; Trainor & Trehub, 1994); however, our results suggest that this developmental progression begins earlier than previously suggested (Costa-Giomi, 2003; Krumhansl & Keil, 1982). Because knowledge of key membership simply involves knowing which notes belong in the key and which do not, whereas harmony perception involves more fine-grained knowledge of the subtle relationships between notes and chords within a particular key, it is not surprising that harmony perception develops later than knowledge of key membership. Future research could examine even younger children to specify the developmental course of each of these skills.

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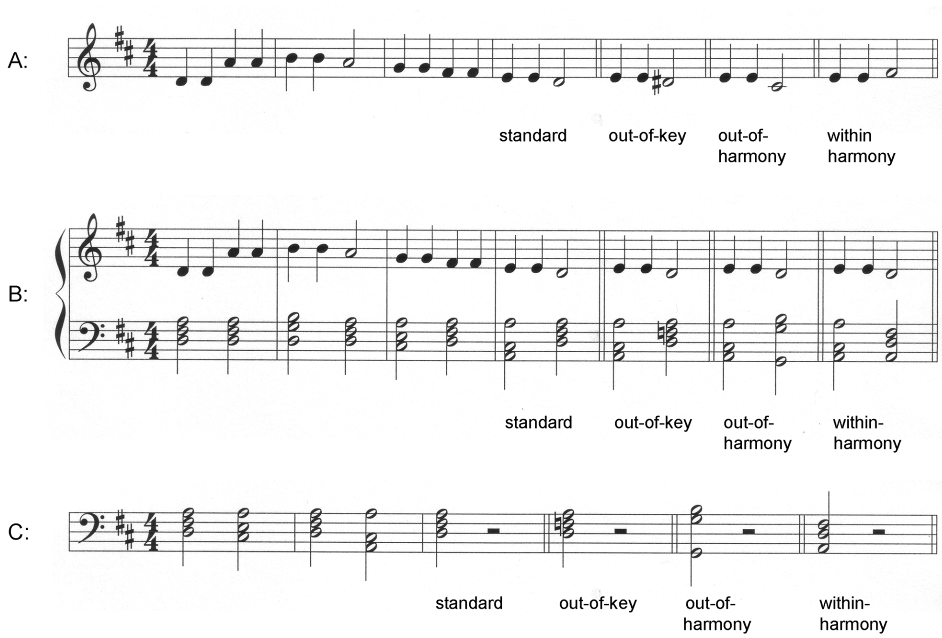

Figure 1. Note and chord sequences of the key membership and harmony perception test. (A) Melody Alone condition. All trials began with the first three measures; the four subsequent measures represent the fourth measure and end of the sequence for each trial type (standard, out-of-key, out-of-harmony, and within-harmony). Deviant notes occurred on the last note of the sequence. (B) Melody Accompanied by Chords condition. All trials began with the first three measures; the four subsequent measures represent the fourth measure and end of the sequence for each trial type (standard, out-of-key, out-of-harmony, and within-harmony). Deviant chords occurred on the last chord of the sequence. (C) Chords Alone condition. All trials began with the first two measures; the four subsequent measures represent the fourth measure and end of the sequence for each trial type (standard, out-of-key, out-of-harmony, and within-harmony). Deviant chords occurred on the last chord of the sequence.

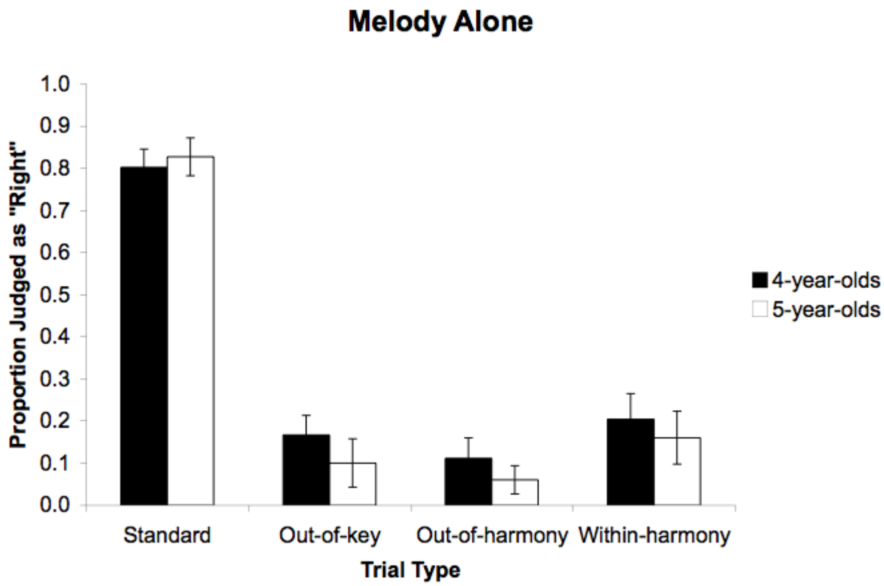

Figure 2. Performance on the Melody Alone condition. Bars represent standard error.

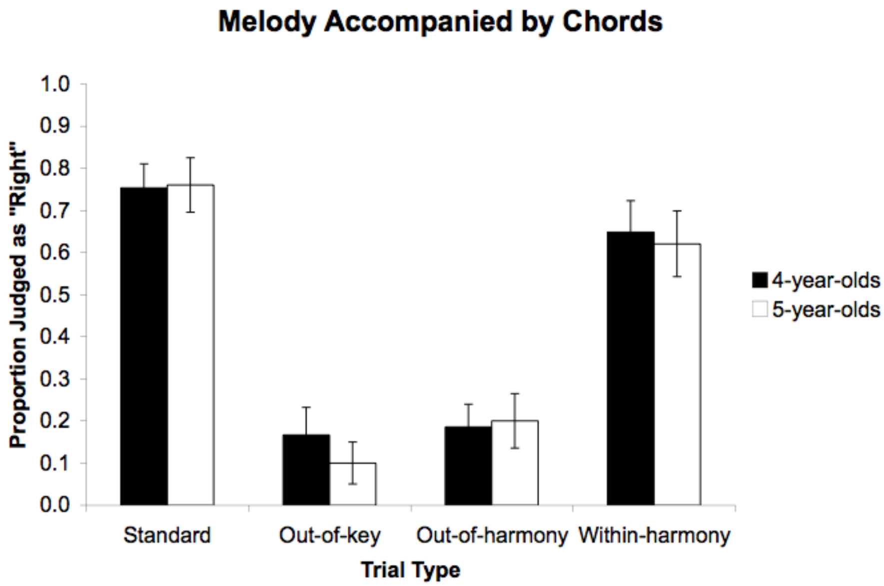

Figure 3. Performance on the Melody Accompanied by Chords condition. Bars represent standard error.

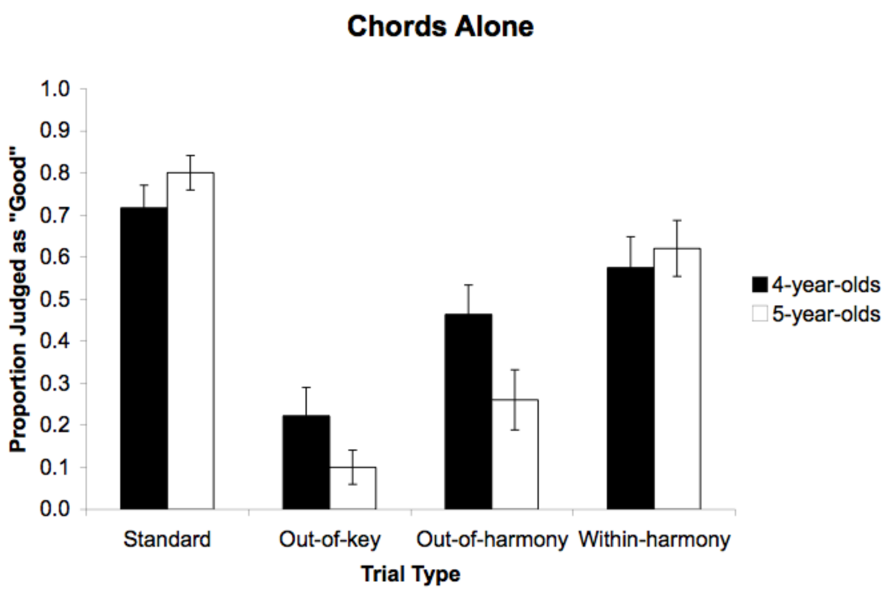

Figure 4. Performance on the Chords Alone condition. Bars represent standard error.

CHAPTER 4: Effects of musical training on key and harmony perception

Corrigall, K. A., & Trainor, L. J. (2009). Effects of musical training on key and harmony perception. *Annals of the New York Academy of Sciences, 1169,* 164-168. doi:10.1111/j.1749-6632.2009.04769.x

Preface

Chapters 2 and 3 examined developmental changes in sensitivity to key membership and harmony. The assumption is that these developmental changes occur as children gain more and more exposure to the music of their culture, and thus begin to internalize the structure of that music. However, it is also possible that other mechanisms underlie these developmental changes, such as cognitive maturation. For example, it is possible that the increases in children's working memory capacity, attention, or receptive language ability between the ages of 4 and 5 years could explain why 5-year-old typically perform better than 4-year-olds on tests musical pitch structure knowledge. Experiment 1 of Chapter 2 addressed this possibility indirectly by including measures of working memory and receptive language ability, and the results suggested that developments in these cognitive skills could not fully explain the behavioural performance differences observed between 4- and 5-year-olds. Furthermore, the tendency for girls to perform better than boys on the task and for girls to also be more involved in music-related activities provided initial support for the primary role of experience in enculturation.

Chapter 4 was designed to directly test how experience affects knowledge of key membership and harmony in young children. We tested children who were enrolled in music lessons and children who were not participating in any formal music training on the same test of key membership and harmony knowledge as in Chapter 3. Both groups of children were tested initially, when the musically-trained group had just begun to take music lessons, and then again 8-12 months later. This pre-post test design confirmed that there were no pre-existing differences in music perception skills in children who took music lessons compared to children who did not, and allowed us to test for the role of experience because the groups initially performed equally. We found that music training led to greater increases in sensitivity to key membership and harmony than was observed in the absence of music training. This provides the first direct evidence that musical experience contributes to the development of enculturation in this age group.

Abstract

Even adults with no formal music lessons have implicit musical knowledge acquired through exposure to the music of their culture. Two of these abilities are knowledge of key membership (which notes belong in a key) and harmony (chord progressions). Studies to date suggest that harmony perception emerges around 5-6 years of age. Using simple tasks, we found that formal music training influences key and harmony perception in 3- to 6-year-olds, and that even non-musicians as young as 3 years have some knowledge of key membership and harmony.

Introduction

Sensitivity to some musical aspects appears in infancy,[1] suggesting constraints of the auditory system or information processing biases. However, other aspects depend on exposure to a particular musical system. Notable experience-dependent aspects are key membership (which notes do and do not belong in a key) and harmony perception (likelihood of sequential and simultaneous note combinations). Even adults with no musical training have implicit knowledge of key and harmony,[2,3] suggesting that these skills develop through mere exposure.

Key membership and harmony perception are acquired relatively late.[4] Trehub and colleagues[5] found that 4- and 5-year-olds could more easily detect a change in a melody if its notes belonged to a key than when they did not, in contrast to infants who could detect both changes with equal ease. Similarly, Trainor and Trehub[2,3] found that 5-year-olds, 7-year-olds, and adults detected a deviant out-of-key note better than a deviant in-key note, while infants detected these equally well. Thus, it appears that sensitivity to key membership develops by 4 or 5 years of age.

Harmony perception appears to develop later than key membership. Schellenberg *et al.*[6] primed 6- to 11-year-olds with chord progressions and asked them to make an unrelated, speeded judgment about the last chord (e.g., whether it was in a piano or trumpet tone). All children responded faster to the last chord when it followed Western harmonic rules than when it did not. Similarly, Koelsch *et al.*[7] recorded 5- and 9-year-olds' event-related brain potentials to chord sequences that occasionally contained weak and strong harmonic violations. Adults showed an early right anterior negativity (ERAN) and a late negativity to both weak and strong harmonic violations.[8] In children, both of these components were elicited by strong but not weak harmonic violations[7]. This suggests that young children possess some, although incomplete, implicit knowledge of Western harmonic structure.

Musical training may accelerate the development of harmony perception. Jentschke, Koelsch, and Friederici[9] found that the ERAN was elicited by strong harmonic violations in both 11-year-old musicians and nonmusicians, but that it was stronger in musicians. The ERAN may have been stronger in the musicians because of their musical training, but it is also possible that there were pre-existing differences between children who began music lessons and those who did not.

The goal of the present study was to investigate whether musical training accelerates the development of key membership and harmony perception in younger children. We tested 3- to 6-year-old beginner musicians and non-musicians on their detection of a deviant chord in two versions of "Twinkle Twinkle Little Star." Children were tested initially and again 8-12 months later, after the beginner musicians had participated in music lessons. Since sensitivity to key membership and harmony are emerging around this time,[3,5-7] we hypothesized that children who had participated in music lessons would show better detection of out-of-key and out-of-harmony deviant notes than would children who had not received any formal music lessons.

Method

Participants. ***Time 1.*** Forty children participated. Nineteen had no formal musical training (nonmusicians: mean [M] = 4.9 years; SD = 0.8 years) and 21 were just beginning music lessons at time 1 (beginner musicians: M = 4.9 years; SD = 0.8).

Time 2. Thirty-one also participated at time 2, 8-12 months after time 1. In the nonmusician group, 10 remained in the study at time 2 (M = 6.1 years; SD = 0.9 years). All 21 in the beginner musician group remained in the study at time 2 (M = 5.6 years; SD = 0.9), and their musical training ranged from 5 to 14 months (M = 7.8 months; SD = 2.1 months).

Materials and Design. Two conditions assessed children's perception of key membership and harmony using a simple task and a familiar song (i.e., "Twinkle Twinkle Little Star"), presented in a piano timbre. Each condition had 2 example trials, 2-4 training trials, and 10 test trials: 6 in standard form, 2 with an out-of-key change on the last chord, and 2 with a change that was in key, but out-of-harmony. The melody-plus-chords condition (Figure 1A) sounded familiar; thus, children judged whether each trial ended correctly or incorrectly. The chords-alone condition (Figure 1B) sounded unfamiliar; thus, children judged whether each trial sounded good or bad. We computed the proportion of trials judged as “right” or “good” for each trial type (standard, out-of-key, and out-of-harmony).

Results

For each condition (melody-plus-chords, chords-alone) at each time (1, 2), we first conducted a 2 × 3 ANOVA with musical training as a between subjects factor (nonmusicians, beginner musicians) and trial type as a within-subjects factor (standard, out-of-key, out-of-harmony), adjusting degrees of freedom according to the Greenhouse-Geisser correction where appropriate. Each of these revealed a trial type effect; thus, we compared performance on standard trials to each of the change trials (out-of-key, out-of-harmony). Whenever an effect involving musical training emerged in the overall ANOVA, we included musical training as a between-subjects factor in the follow-up analyses. Finally, if an effect of musical training persisted in these follow-up analyses, we analyzed each trial separately to compare performance between groups.

The results of the melody-plus-chords condition at time 1 are presented in Figure 2. There was an effect of trial type [$F(1.96,74.48) = 98.12$, $P < 0.01$], but not effects involving musical training (both Ps > 0.20). Further ANOVAs revealed significant differences between standard and out-of-key trials [$F(1,39) = 127.00$, $P < 0.01$] and standard and out-of-harmony trials [$F(1,39) = 156.47$, $P < 0.01$].

The results of the melody-plus-chords condition at time 2 are presented in Figure 2. There was an effect of trial type [$F(1.91,55.49) = 178.91$, $P < 0.01$], but no effects involving musical training (both *P*s > 0.05). Further ANOVAs revealed significant differences between standard and out-of-key trials [$F(1,30) = 270.11$, $P < 0.01$] and standard and out-of-harmony trials [$F(1,30) = 290.64$, $P < 0.01$]. The results of the melody-plus-chords condition at both time 1 and 2 suggest that even children with no formal musical training are sensitive to key membership and harmony in a familiar song.

The results of the chords-alone condition at time 1 are presented in Figure 3. There was an effect of trial type [$F(1.89,71.98) = 56.42$, $P < 0.01$], but no effects involving musical training (both *P*s > 0.50). Further ANOVAs revealed significant differences between standard and out-of-key trials [$F(1,39) = 140.07$, $P < 0.01$] and standard and out-of-harmony trials [$F(1,39) = 32.55$, $P < 0.01$].

The results of the chords-alone condition at time 2 are presented in Figure 3. There was an effect of musical training [$F(1,29) = 18.02$, $P < 0.01$], an effect of trial type [$F(1.86,53.98) = 107.27$, $P < 0.01$], and the interaction approached significance [$F(1.86,53.98) = 2.95$, $P = 0.07$]. Thus, we included musical training as a between-subjects factor in the two subsequent analyses. The first ANOVA revealed a significant difference between standard and out-of-key trials [$F(1,29) = 238.68$, $P < 0.01$], an effect of musical training [$F(1,29) = 6.96$, $P = 0.01$], but no interaction ($P > 0.25$). The second ANOVA revealed a significant difference between standard and out-of-harmony trials [$F(1,29) = 131.22$, $P < 0.01$], an effect of musical training [$F(1,29) = 11.16$, $P < 0.01$], and an interaction [$F(1,29) = 5.19$, $P = 0.03$]. Because effects involving musical training persisted in both of these follow-up analyses, we examined the effect of musical training on each trial type. There was no effect of musical training on standard trials ($P > 0.40$); however, there was on out-of-key trials [$F(1,30) = 4.34$, $P = 0.05$], and on out-of-harmony trials [$F(1,30) = 9.24$, $P < 0.01$]. The results of the chords-alone condition at both time 1 and 2 suggest that while non-musicians have some knowledge of key membership and harmony in an unfamiliar song, musical training leads to greater sensitivity to both of these structures.

Conclusions

The groups were similar at time 1, but musical training effects emerged on the out-of-key and out-of-harmony trials of the chords-alone condition at time 2, after the musicians had participated in formal music lessons. These results suggest that musical training rather than pre-existing differences is the driving force behind musicians' superior performance.

No previous studies have found that children under 5 years are sensitive to harmony. By using simple chord progressions and a highly familiar song, we found that nonmusicians as young as 3 years have some knowledge of appropriate harmonic progressions. Our results converge with previous findings suggesting that children develop sensitivity to key membership earlier than harmony.[3] Because knowledge of key membership simply involves knowing which notes belong in key and which do not, whereas harmony perception involves finer-grained knowledge of the subtle relationships between notes and chords within a key, it is not surprising that the former develops before the latter. Finally, our results suggest that children are sensitive to key and harmony in familiar songs before they can generalize that knowledge to unfamiliar songs.

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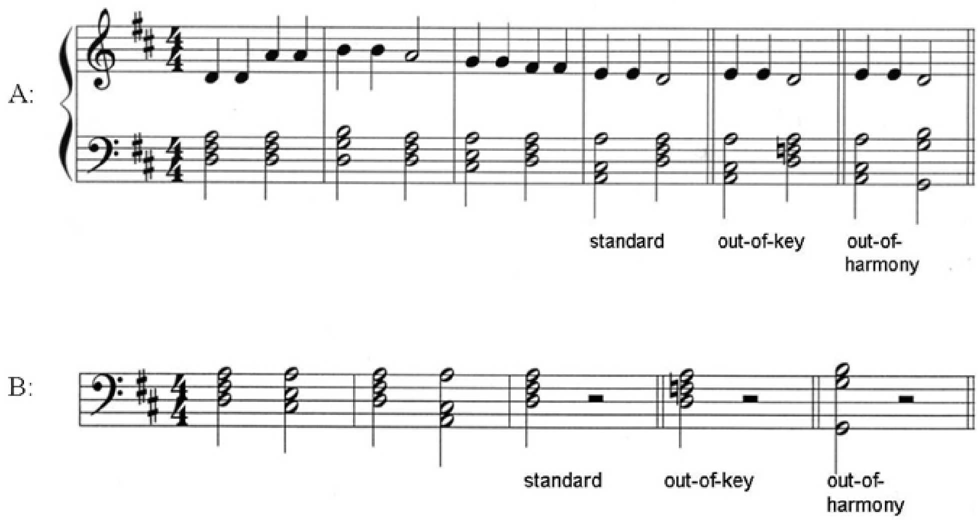

Figure 1. Note and chord sequences. (**A**) Melody-plus-chords condition. All trials began with the first three bars; the last three bars represent the fourth bar and end of the sequence for each trial type (standard, out-of-key, out-of-harmony). (**B**) Chords-alone condition. All trials began with the first two bars; the last three bars represent the third bar and end of the sequence for each trial type (standard, out-of-key, out-of-harmony).

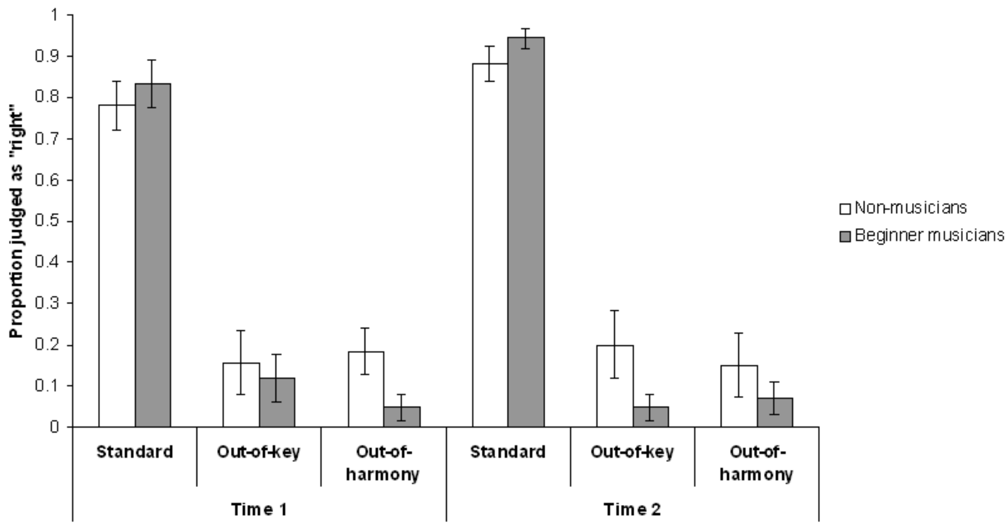

Figure 2. Performance on the melody-plus-chords condition at time 1 and 2. Bars represent standard error.

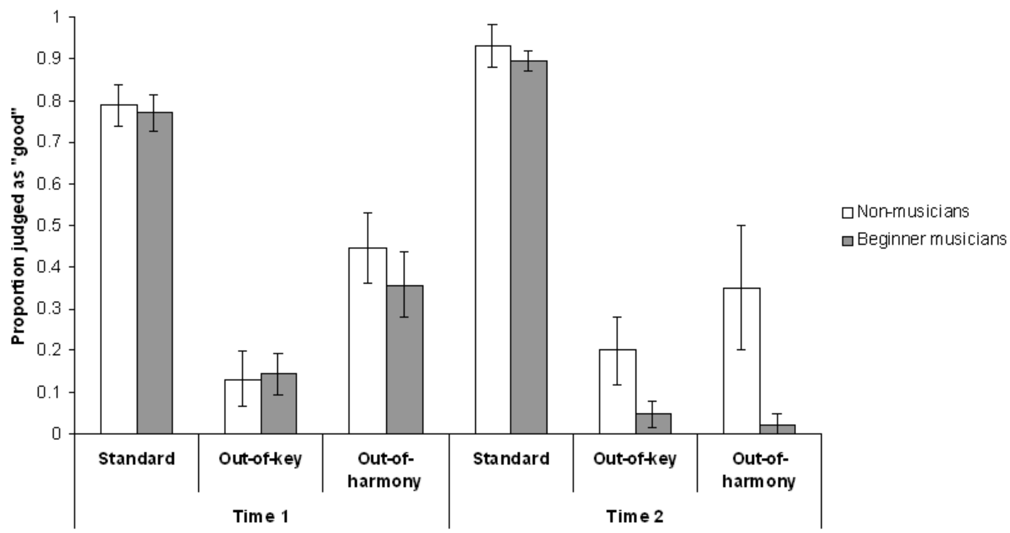

Figure 3. Performance on the chords-alone condition at time 1 and 2. Bars represent standard error.

CHAPTER 5: General Discussion

Musical enculturation is the process by which children acquire knowledge of the structure of the music of their culture. Sensitivity to pitch structure in music is integral to the formation of musical expectations and therefore a fundamental aspect of the perception of musical meaning. Because this skill is so vital to the appreciation for music, it is important to understand its developmental trajectory in childhood. However, previous research had been limited by a lack of methods that are appropriate to study music perception in preschool-aged children. I developed two new behavioural methods to study musical enculturation in young children, both of which were designed to assess children's conscious, evaluative judgments of musical stimuli. In the first, children watched videos of two puppets playing the piano and decided which puppet played the best song. In the second, children decided if a puppet's song had been played correctly or incorrectly, or if it sounded good or bad, and indicated their decision using a happy-face or a sad-face sign. Both of these methods are age-appropriate and engaging, and can maintain young children's attention long enough to elicit explicit judgments. Furthermore, these methods can be modified to study other areas of music perception in young children; indeed, the puppet video procedure has already been adapted to study rhythm and meter perception in preschoolers (Einarson, Corrigall, & Trainor, 2012, July).

My thesis presents a comprehensive study of the development of sensitivity to key membership and harmony during the crucial period in childhood: when these skills are emerging. While some previous studies have examined sensitivity to musical pitch structure without differentiating between different levels of the hierarchy such as key membership and harmony (e.g., Jentschke et al., 2008; Koelsch et al., 2003; Schellenberg et al., 2005), I examined these skills separately in order to study their different developmental trajectories. Because Western music uses a complex harmonic structure, I also examined the development of enculturation within the contexts of chord sequences as well as single-line melodies. Furthermore, the melody and chord stimuli used in my thesis are more ecologically valid than the scale and triad stimuli used in previous research (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Speer & Meeks, 1985; Trehub et al., 1986), because they are more similar to what children would naturally hear in their day-to-day environment. The use of different sequences on each trial in Experiment 1 of Chapter 2 also improved the generalizability of the findings compared to past studies.

To examine the nature of young children's knowledge, I studied children's abstract knowledge of key membership and harmony using explicit behavioural methods and unfamiliar sequences (Experiment 1 of Chapter 2). I also examined implicit or partial knowledge of Western pitch structure in two different ways. First, ERP responses provided a measure of implicit knowledge as they were elicited under passive listening conditions, while children watched a silent movie. Second, partial explicit knowledge was examined in Chapters 3 and 4 through the use of a familiar song as the basis for the musical stimuli. Finally, Chapter 4 provided the first direct test of whether musical experience contributes to the development of enculturation in this age group because it included a pre-test that occurred before the music group had experienced an enriched musical environment. This pre-test/post-test design allowed us to determine whether children who go on to take music lessons have superior music skills to begin with, even before they begin music lessons, whether it is the enriched musical experiences that drive this learning, or whether both pre-existing differences and extracurricular musical exposure contribute to the development of sensitivity to musical pitch structure.

Main Contributions

Through the use of novel behavioural testing methods and EEG, I present evidence for sensitivity to key membership and harmony in the youngest children tested to date. Previous research suggested that children have some behavioural sensitivity to key membership in a single line melody or in a triad by 4 or 5 years of age (e.g., Trainor & Trehub, 1994; Trehub et al., 1986), and neuropsychological sensitivity to key membership and harmony in chord sequences by 5 years (e.g., Jentschke et al., 2008; Koelsch et al., 2003). However, in previous work there has been no evidence of behavioural sensitivity to implied harmony in scales, triads, or melodies before 6 or 7 years (e.g., Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Speer & Meeks, 1985; Trainor & Trehub, 1994), no test of behavioural sensitivity to harmony in chordal sequences, and no evidence of neuropsychological sensitivity to key or harmony in chord sequences before 5 years. My thesis presents evidence for behavioural and neuropsychological sensitivity to both key membership and harmony in children as young as 4 years of age (Experiment 2 of Chapter 2, Chapter 3, Chapter 4).

At the same time, my thesis work suggests that these skills are not fully developed in preschoolers. I provided clear and comprehensive evidence that knowledge of key membership is acquired before knowledge of harmony for both melodic and for chordal sequences, a pattern that was evident in the behavioural results of all three chapters. I also presented two lines of converging evidence that children gather a great deal of partial or implicit knowledge of the musical pitch structure of their culture before that knowledge becomes fully abstract and generalizable to unfamiliar musical sequences. In the first, 4-year-olds showed an ERAN-like response to chords that violated key membership or harmony compared to those that conformed to Western pitch structure (Experiment 2 of Chapter 2), even though their evaluative behavioural judgments indicated no preference for sequences that did or did not violate the rules of Western music (Experiment 1 of Chapter 2). In the second, children showed fairly sophisticated behavioural knowledge of key membership and harmony in the context of a familiar song (Chapters 3 and 4), despite showing no evidence of this knowledge in the context of unfamiliar songs (Experiment 1 of Chapter 2).

Finally, I was the first to show that the ERP response to violations of musical syntax in early childhood differs from the response observed in older children and adults. Previous published studies found the ERAN in adults and in children as young as 5 years old, namely, a response that was early in latency, right-lateralized or sometimes bilateral, found at frontal scalp sites, and negative in polarity (e.g., Jentschke et al., 2008; Koelsch et al., 2003; Koelsch et al. 2001; see Koelsch, 2009 for a review). One unpublished study also found the ERAN in 2.5-year-olds (Jentschke, 2007). However, I found an ERP response to violations of key membership and harmony in 4-year-old children that was similar to the ERAN in many ways but also showed an important difference: like the ERAN, it was early in latency, bilaterally distributed, and found at frontal scalp sites, but unlike the ERAN, the difference wave produced a positivity rather than a negativity. Because a positivity-to-negativity developmental shift has been observed for other ERP responses that are related to pitch (e.g., He, Hotson, & Trainor, 2009; Tew, Fujioka, He, & Trainor, 2009; Trainor et al., 2003), I have suggested that this response is an immature form of the ERAN. These results are the first to suggest a developmental shift in the ERP responses to musical syntactic violations.

Limitations of the Thesis Research and Future Directions

There are several possible reasons why children failed to demonstrate sensitivity to key membership (4-year-olds) and harmony (4- and 5-year-olds) in Chapter 2 (Experiment 1), despite showing behavioural sensitivity in Chapters 3 and 4. As I have suggested, the first is that they have only partial or implicit representations of key membership and harmony, which could lead to harmonic expectations that are too weak or undifferentiated to succeed at a task where all of the excerpts are unfamiliar. By contrast, children would have stronger harmonic expectations for familiar songs, allowing them to demonstrate some behavioural sensitivity to musical pitch structure in Chapters 3 and 4. A second possibility is that children form expectations for the most harmonically appropriate notes and chords, but have not yet developed a strong preference for expected musical events unless the song is highly familiar. In other words, children may expect the tonic note or chord at the end of a musical phrase, but they may not evaluate it as sounding any better than another note or chord unless they are familiar with "how the song goes".

Another possibility is that the behavioural task described in Chapter 2 (Experiment 1) was more difficult than the task used in Chapters 3 and 4. First, the initial instructions to choose the puppet that played the best song, or the subsequent request on each trial to choose "who gets the prize" (Chapter 2, Experiment 1) may have been more difficult to understand than the instructions to decide whether a puppet played a song correctly/good or incorrectly/bad (Chapters 3 and 4). Furthermore, children received more training trials in Chapters 3 and 4 than in Chapter 2 (Experiment 1). Future studies could examine whether the particular instructions given affects children's performance, for example, by comparing instructions to choose which puppet played the song correctly with instructions to choose which puppet's song sounded better. Furthermore, training could also be improved by increasing the number of training trials and/or adding a training criterion for correct responses before moving on to the test trials. Finally, 4-year-old children could be tested with stimuli that they are expected to succeed with using the task described in Chapter 2 (Experiment 1), such as consonant and dissonant intervals. Success with these modified stimuli would suggest that they do understand the task but are not yet sensitive to key membership or harmony, whereas failure might suggest that the task is too difficult.

Second, although the task in Chapter 2 (Experiment 1) was designed to be engaging in order to maintain young children's attention, the visual aspects may have distracted children from listening attentively. Furthermore, children's preferences for particular puppets may have overridden their preferences for harmonically appropriate compared to inappropriate musical sequences. Future studies could compare responses to the same musical stimuli with or without the accompanying video and puppets to examine whether they help, hinder, or make no difference in performance.

Third, the same excerpt was repeated within each condition in Chapters 3 and 4, leaving open the possibility that children learned the most frequently presented ending (i.e., the tonic) during the experiment. By contrast, different excerpts were presented in different keys on each trial in Chapter 2 (Experiment 1), preventing children from using any acoustic frequency cues. It is unlikely that children's success in Chapters 3 and 4 resulted solely from learning with the experimental context, however. If this were the case, children should have performed best on the condition presented last (Chords Alone), at which time cumulative exposure to the chord progression used in the experiment was greatest. However, the Chords Alone condition was actually the most difficult for children, most likely because it was the least familiar. Nonetheless, for better generalizability, future studies should test children's sensitivity to key membership and harmony in familiar songs where a different familiar excerpt is presented on each trial.

Finally, the task used in Chapter 2 (Experiment 1) was more demanding on memory than the task used in Chapters 3 and 4, which may have prevented young children from succeeding despite the fact that there was no correlation between performance on the music task and performance on the forward digit span memory task. For example, these tasks may not have been sensitive enough to measure individual differences in these children. Although children were able to demonstrate sensitivity to both key membership and harmony in Chapters 3 and 4 when the sequences were presented one-at-a-time, pilot testing using the stimuli from Chapter 2 suggested that young children were no better at the task when only one sequence was presented on each trial and children judged whether the song sounded good or bad. One avenue for future research is to examine whether children can simply discriminate between sequences that do or do not violate key membership or harmony. A failure to discriminate could suggest that there are too many memory demands in a task in which two sequences are to be compared.

Another avenue for future research is to examine the development of ERP responses to key and harmony violations. It is somewhat peculiar that I found an early positivity in response to violations to musical pitch structure (Chapter 2, Experiment 2), whereas others have found an early negativity in children of a similar age (Jentschke et al., 2009), and in much younger children (Jentschke, 2007), although it is possible that children whose data were included in previous studies were especially precocious and thus showed a more mature response. Younger children should be tested to examine the emergence of ERP responses to key membership and harmony violations, and older children should be tested to examine the maturation of these responses from broader positivities to sharper negativities. Furthermore, it would be interesting to investigate whether the emergence of the ERAN coincides with behavioural sensitivity to Western musical pitch structure.

Finally, my thesis focused on the development of sensitivity to key membership and harmony in the most common pitch structure in Western music: the major mode. However, the minor mode is also prevalent in Western music. Very little research has examined adults' knowledge of the minor tonal hierarchy (e.g., Krumhansl, 1990; Krumhansl & Kessler, 1982; Vuvan, Prince, & Schmuckler, 2011), and no known studies have tested children's sensitivity to key membership or harmony within minor contexts. Because the minor mode is more complex, having three different forms (the natural, harmonic, and melodic forms), and because the major mode is more common, enculturation to the minor mode may have a much longer developmental trajectory. At the same time, Schellenberg and von Scheve (2012) have recently shown that the use of the minor mode in popular music has increased over the past five decades, suggesting that young children may have more exposure to it than previously assumed. Thus, an interesting avenue for future research is to examine the development of sensitivity to key membership and harmony in the minor mode.

Implications of the Thesis Research for Other Research Areas

My thesis research has important implications for understanding how children perceive music's ultimate purpose: the communication of emotional meaning. If young children cannot yet form musical expectations that are based on the hierarchical structure of pitch in the same way that adults do, then they may also experience music in a very different way than adults. In contrast to adults, children's perception of emotion and meaning in music may emerge from other features such as the rhythmic and metrical structures, the tempo, or the melodic contour. For example, some research suggests that even school-aged children rely heavily on rhythmic and metrical cues when judging the emotional valence of music (e.g., Kratus, 1993), and young children rely heavily on tempo (Dalla Bella, Peretz, Rousseau, & Gosselin, 2001). By contrast, the use of pitch structure cues in emotional judgments appears to emerge much later in development. Whereas Western adults readily associate the major mode with happiness and the minor mode with sadness (e.g., Gagnon & Peretz, 2003; Hevner, 1936; Husain, Thompson, & Schellenberg, 2002), children fail to make this association until about 6-7 years (e.g., Dalla Bella et al., 2001; Gerardi & Gerken, 1995; Gregory, Worrall, & Sarge, 1996; but see Kastner & Crowder, 1990). Although no known studies to date have examined the emotional responses associated with musical expectancies in children, it is very likely that they would differ from those in adults. This is an important question for future research to address and has the potential to reveal developmental differences in the aesthetic appreciation and liking for music.

The development of sophisticated musical knowledge also provides insight into the human brain's remarkable capacity for learning complex information. For example, both musical and linguistic phrases are composed of the recombination of a finite set of small units (i.e., notes, intervals, and chords in music and phonemes and words in language) into larger sequences that can take on more complex meaning according to hierarchical rules. That infants and children can effortlessly learn the significance and meaning of these abstract units as well as their structural rules supports the notion that music and language are both integral aspects of human behaviour. Furthermore, it suggests that humans may possess general learning mechanisms that support both domains.

Statistical learning has been proposed as one possible candidate mechanism that underlies music and language acquisition, whereby listeners use the statistical properties of the input to extract structure. Studies have shown that even infants and children can use statistical learning in a variety of contexts such as to learn words (Saffran, Aslin, & Newport, 1996), tonal patterns (Saffran, Johnson, Aslin, & Newport, 1999), visual patterns (Fiser & Aslin, 2002; Kirkham, Slemmer, & Johnson, 2002), and action sequences (Buchsbaum, Gopnik, Griffiths, & Shafto, 2011), and there is some evidence in adults that it can also assist in learning syntactic rules (e.g., Saffran, 2003; Thompson & Newport, 2007). However, it is interesting to note that children appear to begin learning linguistic syntax before they show knowledge of the structure of Western musical pitch. For example, research using the preferential looking method has shown that children as young as 1.5 years are sensitive to word order, an important aspect of syntactic knowledge (Hirsh-Pasek, Golinkoff, deGaspe-Beaubien, Fletcher, & Cauley, 1985, see also Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987). In terms of production, the majority of children's sentences are grammatically complete by approximately 2 years for simple sentences, and by 2.5 years for complex sentences (Vasilyeva, Waterfall, Huttenlocher, 2008), although children's linguistic syntactic knowledge continues to develop into childhood. By contrast, the acquisition of musical syntactic knowledge appears to take much longer to develop. While precursors to this knowledge may appear in infancy, such as a preference for consonant over dissonant intervals (Masataka, 2006; Trainor & Heinmiller, 1998; Trainor et al., 2002; Zentner & Kagan, 1998), children do not appear to be sensitive to musical syntax until at least 4 years of age, with further development occurring for years after this point. One question that future research should address is whether the different developmental timelines for linguistic compared to musical syntax knowledge result from the amount and nature of exposure to each. For example, children likely receive much more language than music input, and the amount and quality of music exposure that each child receives likely varies across children much more than with language. Furthermore, whereas language exposure involves active communication attempts on the part of the learner as well as feedback from the communication partner, music exposure is much more predominantly passive in early childhood.

Broader Applications of the Thesis Research

By understanding more about how musical perceptual and cognitive skills develop in childhood, we can also begin to apply this knowledge for educational purposes. One important finding from my thesis is that formal music training affects the rate of enculturation to musical pitch structure, which implies that children may benefit from enrolling in music lessons early (i.e., in preschool). Understanding the structure of music is an important part of the formal study of music; therefore, parents who intend to enroll their children in music lessons may wish to do so earlier in order to give their child a head start at acquiring key and harmony perception, among other musical skills. As discussed above, however, acquiring pitch-based musical expectations may also change the way that emotion is perceived in music and allow listeners to pick up on subtle cues that have intense emotional effects. Having the ability to perceive emotional meaning from these expectation-related structural cues may help children develop a lifelong passion for music by enriching their musical experiences. Furthermore, as research suggests that music is often used as a tool for emotional regulation (e.g., North, Hargreaves, & O'Neill, 2000; Saarikallio & Erkkilä, 2007; Sloboda &

O'Neill, 2001; Wells & Hakanen, 1991), it is possible that acquiring expectation-related emotional perception in music may allow children to take fuller advantage of music's emotional self-regulation effects.

Exploring the effects of formal and informal musical experience on music perception skills is also important in order to understand whether experience has a different impact depending on when it occurs during development. Although it is unknown whether there is a sensitive period for the acquisition of sensitivity to musical pitch structure, one study suggests that infants may learn foreign musical structures more easily than adults. Hannon and Trehub (2005b) found that after 1-2 weeks of at-home exposure to Balkan music composed with complex-integer ratio metrical structures, 12-month-old North American infants performed like Balkan adults on a meter-related change detection task, whereas North American adults continued to perform in manner consistent with a Western simple-integer ratio meter bias. If sensitivity to musical pitch structure follows this same developmental trend, then this would imply that parents should expose their children to the music of foreign cultures at a very young age if they wish for their children to learn these musical systems naturally, easily, and efficiently. In a recent study with adults, Wong, Roy, and Margulis (2009) showed the expected cognitive and affective enculturation biases in Western and Indian listeners who were exposed almost exclusively their own culture's music; namely, listeners exhibited better memory and lower tension ratings for culturally familiar compared to culturally unfamiliar music. However, so-called "bimusical" participants who were exposed to the music of both cultures approximately equally exhibited no such memory or affective biases. Although these results suggest that bimusical participants were sensitive to both Western and Indian music, it remains unknown whether these sensitivities are more easily acquired in childhood than in adulthood.

Finally, as music perception and cognition research uncovers more truths about how children acquire musical knowledge as part of normal development, we can begin to apply this knowledge to understanding disorder. Congenital amusia or "tone-deafness" refers to a lifelong impairment at recognizing or perceiving music despite having normal intelligence and working memory, no hearing loss or structural brain abnormalities, and regular exposure to music during development (e.g., Ayotte, Peretz, & Hyde, 2002; Peretz et al., 2002). Although the assumption is that individuals with congenital amusia have had it since birth, the disorder typically is not identified until adulthood, if at all, most likely because it has little impact on an individual's daily functioning. Because congenital amusia is thought to be a disorder in pitch processing, (e.g., Peretz et al., 2002), it is important to understand when and how different pitch processing skills are acquired during normal development so that we may identify impairments early on. The plasticity of the developing brain suggests that interventions may be more effective in childhood than in adulthood, and thus early identification of pitch processing difficulties may be necessary for a successful outcome. The implications for understanding how children acquire musical expectations are not only limited to music-specific disorders, however. There is also evidence that children with Specific Language Impairment who are impaired at processing linguistic syntax also exhibit abnormal processing of musical syntax (Jentschke et al., 2008). These results provide further evidence that music and language rely on common processes, and support the need for more research on how musical development typically progresses.

Summary

In my thesis, I examined how musical culture shapes our perception of the world around us at a crucial point in development. The results of these studies showed that it takes many years to acquire knowledge about the structure of musical pitch in Western music, but that even young children can exhibit sophisticated musical knowledge. Furthermore, these findings occurred in a culture where there is a sharp divide between musicians, who are thought to possess musical knowledge, and the audience, who are thought to be musically naïve. My thesis work helps to confirm that music is a fundamental and universal human behaviour rather than a skill possessed by only a select few of highly trained individuals, and that the acquisition of musical knowledge is an important but understudied aspect of normal development.

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