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Melodic expectations in 5- and 6-year-old children

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ABSTRACT

It has been argued that children implicitly acquire the rules relating to the structure of music in their environment using domain-general mechanisms such as statistical learning. Closely linked to statistical learning is the ability to form expectations about future events. Whether children as young as 5 years can make use of such internalized regularities to form expectations about the next note in a melody is still unclear. The possible effect of the home musical environment on the strength of musical expectations has also been under-explored. Using a newly developed melodic priming task that included melodies with either “expected” or “unexpected” endings according to rules of Western music theory, we tested 5- and 6-year-old children ($N = 46$). The stimuli in this task were constructed using the information dynamics of music (IDyOM) system, a probabilistic model estimating the level of “unexpectedness” of a note given the preceding context. Results showed that responses to expected versus unexpected tones were faster and more accurate, indicating that children have already formed robust melodic expectations at 5 years of age. Aspects of the home musical environment significantly predicted the strength of melodic expectations, suggesting that implicit musical learning may be

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influenced by the quantity of informal exposure to the surrounding musical environment.

Introduction

Perceptual mechanisms for the processing of musical pitch appear to be in place from infancy, setting the basis for the learning of higher-level pitch arrangements such as musical scales, which are foundational for understanding large-scale musical structure (Trainor & Unrau, 2012). Although every musical system in the world is composed of sets of scales that divide the octave into intervals, specific tones and intervals vary across different cultures. In the same way that individuals learn the structure of their language through mere exposure to their native linguistic environment (e.g., Kuhl, 2004), they also acquire implicit knowledge of the scale structure that forms the musical system of their culture (e.g., Lynch, Eilers, Oller, & Urbano, 1990).

The remarkable ability of humans to implicitly acquire the rules and regularities of music in their environment has been argued to depend partly on implicit domain-general mechanisms such as statistical learning (Corrigall & Trainor, 2014; Daikoku, Yatomi, & Yumoto, 2014, 2015; François & Schön, 2011; Tillmann, Bharucha, & Bigand, 2000). Indeed, data on the statistical distribution of notes and chords in Western music have shown that some musical elements occur more frequently than others (Krumhansl, 1990), and studies have provided evidence that adults are sensitive to pitch distributions (Krumhansl, 2000). Moreover, it appears that this sensitivity can occur even after brief exposure to novel tonal structures (Oram & Cuddy, 1995). Therefore, individuals may acquire knowledge of musical structure through internalizing the distributional patterns of musical events in the music of their environment (Bigand & Poulin-Charronnat, 2006; Tillmann, 2005; Tillmann et al., 2000). Indeed, in an elegant experiment, Saffran, Johnson, Aslin, and Newport (1999) showed that adults and 8-month-old infants were able to use statistical information in a continuous stream of tones to extract sequences in a process similar to that employed with linguistic information (see also Jonaitis & Saffran, 2009; Thiessen, Hill, & Saffran, 2005). Other work has also demonstrated that statistical learning of both linguistic and musical auditory stimuli in adults is reflected in increased magnetoencephalographic responses to tones and vowel formants that occur rarely in a sequence compared with those that occur frequently (Daikoku et al., 2014, 2015).

Intrinsically linked to statistical learning is the human ability to form expectations about future events (Tillmann et al., 2000). Expectations have been conceptualized as the anticipation of an event based on its likelihood of occurring (Chaplin, 1985), and more highly expected events have been shown to provide a perceptual facilitation in systems governed by structural rules such as language and music (Tillmann & Poulin-Charronnat, 2010). For instance, individuals process a target word faster and more accurately when it is paired with a semantically congruent word rather than a semantically incongruent word (e.g., Meyer & Schvaneveldt, 1971; Neely, 1976, 1977). Similarly, a facilitation effect has been observed in studies using musical stimuli; listeners make decisions about target chords (e.g., identifying the timbre, making judgments about intonation/consonance) faster and more accurately when the preceding context is harmonically related than when it is harmonically unrelated (Bharucha & Stoeckig, 1986; Bigand, Madurell, Tillmann, & Pineau, 1999; Bigand & Pineau, 1997; Marmel, Tillmann, & Delbe, 2010; Marmel, Tillmann, & Dowling, 2008; Tillmann, Bigand, & Pineau, 1998). Harmonic structure can also be implied by isolated melodies, which set up expectations in listeners for an underlying chord progression (Trainor & Unrau, 2012). Adult listeners have been shown to make judgments faster and more accurately for more expected versus less expected tones within a melody, using both pitch perception (Marmel & Tillmann, 2009; Marmel et al., 2008) and timbre discrimination tasks (Marmel & Tillmann, 2009; Marmel et al., 2010).

Computational models, capable of simulating aspects of musical learning, can help to develop a better understanding of the implicit acquisition of musical structure. The information dynamics of music (IDyOM) is a computational model of auditory expectation based on probabilistic prediction arising from statistical learning (Pearce, 2005, 2018). The IDyOM model simulates the cognitive processes underlying musical expectation by generating expectations for the next note of a melody based on regularities learned through previous experience, just as statistical learning theory predicts. It comprises two components: a long-term component exposed to a large corpus of Western tonal melodies, which simulates the formation of expectations through long-term exposure to music, and a short-term component trained incrementally for each melody. The short-term component represents immediate influences on expectations that are formed through online processing of the unfolding melody. The predictions of the long- and short-term components of the model are combined to provide an overall prediction for the pitch of the next note. In contrast to the models proposed by Narmour (1990) and Schellenberg (1997), which make local predictions based on one or two preceding notes, the IDyOM model can predict the probability of a note occurring based on preceding contexts of variable length (Pearce, 2005; Omigie, Pearce, Williamson, & Stewart, 2013).

Previous studies with adults using the IDyOM model have shown that it is reliable in probing implicit melodic expectations in both typical and atypical (i.e., amusic) adult populations (Omigie, Pearce, & Stewart, 2012; Omigie et al., 2013; Sears, Pearce, Spitzer, Caplin, & McAdams, 2019). Because IDyOM relies on statistical learning through exposure, it is also interesting to examine how well the model simulates expectations at earlier stages of development. However, it has not yet been applied to musical perceptual processes in children. Therefore, this study's first aim was to use the IDyOM model to investigate young children's formation of expectations in melodies. To achieve this aim, we tested 5- and 6-year-old children with an implicit task, specifically a melodic priming paradigm, which focused on the degree of expectedness of endings in simple melodic phrases. The IDyOM model was used to select phrases from a collection of folk songs that ended in a high-probability note and to create versions in which the final note was replaced by one with a low pitch probability. Faster response times (RTs) and higher accuracy rates for high-probability notes rendered in the same timbre as the preceding context (i.e., piano) were taken as evidence of a melodic priming effect (i.e., evidence that children of this age are already able to form melodic expectations). In other words, we anticipated that if children have implicit knowledge of Western musical structure, high-probability endings will prime their responses and RTs will be shorter following the pattern of adult responses in a similar task making use of the IDyOM model (Hansen & Pearce, 2014; Omigie et al., 2013). Unlike previous implicit tasks for children that used chord sequences specifically composed for each experiment (Marin, 2009; Schellenberg, Bigand, Poulin-Charronnat, Garnier, & Stevens, 2005), our task uses (parts of) real melodies from an existing database of folk tunes (i.e., the Essen Folk Song Collection). Therefore, although stimuli are carefully controlled, they also resemble to a greater extent what children would hear in the everyday environment, contributing to the ecological validity of the task. Another reason to focus on melodies is that they constitute an important part of Western musical traditions as well as non-Western ones, and therefore the results may generalize more naturally across different cultures.

Although implicit melodic priming tasks such as the one used in this study have not yet been used with developmental populations, studies have specifically investigated melodic expectations in children using explicit responses. Specifically, Schellenberg, Adachi, Purdy, and McKinnon (2002) showed that 7- to 11-year-old children who were asked to make evaluative ratings for continuations of short melodies, expected tones to be proximate in pitch to the preceding ones, which is one of the two principles that, according to Schellenberg (1997), influences listeners' melodic expectations (i.e., pitch proximity). However, school-aged participants in the same study failed to show patterns of more complex expectations given that their responses did not conform to Schellenberg's (1997) principle of pitch reversal (i.e., large intervals are followed by a change of pitch contour). These results may reflect the use of tasks requiring an explicit response from the children rather than implicit measures. Explicit tasks can be harder for children to perform because they usually pose a number of demands (e.g., in terms of inhibition, executive functioning, or verbal skills) and may mask young children's actual competence (Carruthers, 2013; Oktay-Gür, Schulz, & Rakoczy, 2018). These considerations motivated our choice of implicit task to address melodic expectations in 5- and 6-year-old children in the current study.

A second aim of this study was to explore whether the home musical environment is linked to the formation of implicit expectations in music. Indeed, implicit knowledge of musical structure has been previously conceived as being directly linked to learning through everyday informal exposure to the music of one's culture (see Hannon & Trainor, 2007, for a review). Studies that have quantified children's musical exposure in the home using all-day recordings indicate that a large amount of everyday musical experience (either recorded or live) is available to infants during the first year of life (Mendoza & Fausey, 2019), although there also seems to be great variability among families in the type and quantity of musical input provided, especially with regards to recorded music (Costa-Giomi & Benetti, 2020). Crucially, infants readily respond to this input; for instance, a case study with a 15-month-old infant showed that he was able to imitate music features of songs that he heard such as pitches, melodic contours, and rhythms (Benetti & Costa-Giomi, 2020). Few studies with infants and young children have also investigated whether experience with music is associated with more refined music-related auditory skills. For instance, two studies have shown that participation in structured musical activities can increase sensitivity to Western tonality in infants younger than 12 months (Gerry, Faux, & Trainor, 2010; Gerry, Unrau, & Trainor, 2012). In another study, 6-year-old children receiving 15 months of musical training manifested a greater increase in the size of brain areas in the right motor cortex and auditory cortex compared with a carefully matched control group for age, gender, and socioeconomic status (Hyde et al., 2009). These structural changes in the music group compared with controls were predicted by improvement scores in behavioral tasks assessing motor sequencing and melody and rhythm discrimination. These findings indicate that at least some aspects of musical development can be shaped by relevant musical experience; however, no study so far has investigated the influence of everyday musical experience in the home on the formation of musical expectations in young children.

In summary, the current study developed a novel implicit task to probe melodic expectations in 5- and 6-year-old children addressing two research questions:

1. Do 5- and 6-year-old children show evidence of acquired implicit knowledge of melodic musical structure?
2. Is the home musical environment associated with this ability?

In our task, participants were presented with short melodies embedded in an ad hoc iPad application with colorful graphics and were required to make speeded judgments about the timbre of the ending note by tapping on the image of the relevant instrument on a touchscreen. Half of the melodies ended in high-probability notes and the other half ended in low-probability notes as computed by the IDyOM model. All melodies preceding the target (i.e., ending) notes were rendered in piano, whereas half of the high-probability target notes and half of the low-probability ones were altered to a trumpet timbre. The choice of piano as the main instrument was motivated by pilot testing, which revealed that this timbre was the most familiar and easily identifiable among children of this age group. Trumpet was also among the most familiar both visually and acoustically.

We hypothesized that faster RTs and higher accuracy rates for high-probability notes rendered in the same timbre as the context (i.e., piano) would provide evidence that the children have already formed melodic expectations. This rationale was based on a number of studies investigating melodic priming in adults (Marmel & Tillmann, 2009; Marmel et al., 2010; Omigie et al., 2012; Tillmann, Bigand, Escoffier, & Lalitte, 2006) that have demonstrated that only trials where target notes/chords that are the same timbre as the preceding context provide facilitation in speed of response because the change in timbre itself influences RTs as an additional effect. The difference (in milliseconds) between RTs and difference in accuracy rates between high- and low-probability notes were taken as measures of the strength of melodic expectations. To assess informal musical experience in the family, parents completed the Music@Home Questionnaire, an instrument with good psychometric properties that addresses a number of dimensions that constitute the home musical environment, such as parents' initiation of singing and music making, or children's active engagement with music (Politimou, Stewart, Müllensiefen, & Franco, 2018).

Method

Participants

Using a priori power analysis, we calculated that the sample size needed to achieve 95% power with a two-sided 5% significance level and a medium effect size (η^2 = .06) was N = 44. A total of 46 participants (24 girls) between 4 years 9 months and 6 years 10 months of age were recruited from a single school in London. The mean age of participants was 5 years 9 months (SD = 7.54 months). Half of the children (n = 23) were attending reception (M_{age} = 5.22 years, SD = 2.78 months) and half (n = 23) were attending Year 1 (M_{age} = 6.30 years, SD = 4.49 months). Children suspected of or diagnosed with developmental, learning, or language disabilities (as reported by the parents) were excluded from the study. Of the 50 children who were initially recruited, 4 children were excluded (1 child was suspected of attention difficulties as reported by the parents and nursery teachers, 1 child had received a diagnosis for language difficulties, and 2 children failed to reach the criterion in the task assessing melodic expectations. Of the final sample of 46 participants, 39 children were monolingual English speakers and 7 children also spoke a second language at home with either the primary or secondary caregiver. It is worth noting that, given the scarcity of studies investigating melodic expectations in young children, our initial intention was to include children younger than 5 years. However, pilot testing with 3- and 4-year-old children (N = 10) showed that a considerable proportion of these children (35%) failed to reach the criterion for completing the task (inclusion criterion is described in the "Procedure" section). Furthermore, young children who reached criterion and completed the task made several errors, thereby minimizing the number of trials that could be used in the analyses.

Self-report questionnaires providing demographic information were completed by parents and caregivers. Of 46 caregivers, 4 failed to complete the questionnaires or provided insufficient information; thus, the final sample for these measures was N = 42. As a measure of socioeconomic status, we used the National Statistics Socio-economic Classification system (NS-SEC). The NS-SEC is the latest revised socioeconomic classification recommended by the Economic and Social Research Council (ESRC) and derives information from occupation and employment status/size of organization to classify individuals in five classes (Rose, Pevalin, & O'Reilly, 2005). According to the NS-SEC, 83% of the families' main earners were employed in managerial and professional occupations (n = 34), 12% were employed in intermediate occupations (n = 5), 2% were employed in lower supervisory and technical occupations (n = 1), and 2% were employed in semi-routine and routine occupations (n = 1) (1 participant failed to provide information on socioeconomic status). Approximately 54% of the primary caregivers held a master's degree or above (n = 22), 34% held an undergraduate degree or professional qualification (n = 15), 10% had completed an advanced level pre-university qualification or equivalent (n = 3), and 2% had not completed mandatory education (n = 1) (1 participant did not provide information on education).

The research undertaken and presented in this article received ethical approval from the ethics committee of Middlesex University as conforming to the ethical principles of the British Psychological Association and the WMA Declaration of Helsinki. An acceptance letter was obtained from the participating school, and the opt-out parental consent procedure was used following all necessary regulations; two families opted out.

Materials

Stimuli

A total of 40 five-note melodic phrases were taken from a corpus of folk melodies, the Essen Folk Song Collection (Schaffrath, 1995) and rendered in piano timbre using the Steinway grand piano sound from the Garageband for Mac (Version 10.3.2). The melodies had a length of five notes to ensure that a clear melodic context was established before children needed to respond to the final note. Given that the focus was on melodic expectations, the rhythmic structure of the melodies was removed so that each note within the melody had a duration of 500 ms and the final note had a duration of 1000 ms. The tempo of the stimuli was 120 beats per minute (bpm) and was chosen based on previous work with young children indicating that preschool children synchronize with greater ease at faster tempos ranging from 100 to 150 bpm (Provasi & Bobin-Bègue, 2003).

The average pitch across all melodies was 69.50 in MIDI note numbers (~440 Hz). Half of the stimuli were original melodic phrases taken from the corpus and had high-probability endings as calculated using the IDyOM model (Pearce, 2005). The other half of the stimuli had low-probability endings chosen by randomly sampling from the pitch distribution returned by the IDyOM model such that the note selected as a replacement had a lower conditional probability than the original final note. We analyzed the note endings in terms of their information content (IC; negative log probability to the base 2) such that high-probability notes have low IC and low-probability notes have high IC. Therefore, the IC for the target notes was within either the low range of values (IC: M = 12.34, SD = 1.84, range = 8.01–14.40) or the high range of values (IC: M = 1.62, SD = 0.96, range = 0.14–4.09). Different original melodies were used for the stimuli with low- and high-probability endings to avoid any effects of repetition. Stimuli were initially rendered in a piano timbre, and then half of the high-probability target notes and half of the low-probability ones were altered to a trumpet timbre using the Garageband for Mac (Version 10.3.2). Both timbres were chosen based on pilot testing, which revealed that they were the most familiar and easily identifiable instruments among this age group. Finally, the stimuli were divided into two blocks of 20 stimuli each: A (melodies 1–20) and B (melodies 21–40).

The IC of the melodies was balanced between different timbres and blocks of trials. A three-way analysis of variance (ANOVA) with IC as the dependent variable and block (A or B), target timbre (same context–piano or different context–trumpet), and target type (high probability or low probability) as independent variables yielded a significant main effect of target type, $F(1, 36) = 610.89$, $p < .001$, $\eta^2 = .94$, and no other main or interaction effects. This confirms that IC differs significantly between the high- and low-probability conditions but does not differ between the various combinations of timbre and block.

To control for sensory effects on expectation, the size and direction of the final interval of each melody was balanced within the low-probability condition such that there were equal numbers of large (six or more semitones) intervals (n = 10) and small intervals (n = 10) and of descending intervals (n = 10) and ascending intervals (n = 10). Balancing large and small intervals for the high-probability condition was not possible given that these were actual phrases taken from folk songs, but there were equal numbers of ascending and descending intervals (n = 10). Furthermore, a three-way ANOVA with pitch interval as the dependent variable and block (A or B), target timbre (same context–piano or different context–trumpet), and target type condition (high probability or low probability) yielded no significant effects of block or target type but a significant effect of target timbre, $F(1, 36) = 4.84$, $p < .05$, $\eta^2 = .12$. These results demonstrate that pitch interval did not differ between the two main conditions of interest (high probability and low probability). The fact that pitch interval significantly differed between the two timbre conditions (same context–piano and different context–trumpet) was not a concern because previous work with melodic priming in adults (Marmel & Tillmann, 2009; Marmel et al., 2010; Omigie et al., 2012; Tillmann et al., 2006) has shown that speed of response is facilitated only for target notes that are rendered in the same timbre as the preceding context. This motivated a separate analysis of those trials ending with trumpet timbre and those trials ending with piano timbre, whereas we expected to find a priming effect only in the trials ending with piano.

The TimbreApp paradigm

A child-friendly application, TimbreApp, featuring a timbre identification task was created and run on an iPad 2. On each trial, participants listened to a five-note melody and made speeded judgments about the timbre of the target note by tapping on the image of either a piano or a trumpet on a touchscreen.

Each child completed 40 trials (corresponding to 40 melodies) spread across two sessions. The order of presentation was counterbalanced across participants, with half of the children completing Trials 1 to 20 (Block A) and the other half completing trials 21 to 40 (Block B) on their first session. The order of trials was randomized within each block. Half of the children were presented with a piano left/trumpet right configuration (Configuration 1), and the other half were presented with a piano right/trumpet left configuration (Configuration 2). This way, any laterality bias remained constant across all trials for individual participants. Overall, four block/configuration combinations were created (see Table 1) and participants were randomly assigned to an order of A1–B1, B1–A1, A2–B2, or B2–A2.

The timbre identification task was presented to the children as a game. Each trial was presented along with the drawing of a bear conductor, Mr. Giles, and children were told that Mr. Giles needs help with identifying the sound of the instruments because he cannot hear very well. Therefore, participants were asked to “tell Mr. Giles what the last sound of each song is” by tapping on the image of the correct instrument as fast as possible. Audio–visual positive and negative feedback for correct

Table 1
Block and configuration combinations.

Block	Configuration
A = Melodies 1–20	1 = Piano right/trumpet left
A = Melodies 1–20	2 = Piano left/trumpet right
B = Melodies 21–40	1 = Piano right/trumpet left
B = Melodies 21–40	2 = Piano left/trumpet right

and incorrect timbre identification was given at the end of each trial to increase motivation and ensure that children performed to their best of their abilities (see Fig. 1).

Language screening test

A language screening test, the British Picture Vocabulary Scale (Dunn, Whetton, & Burley, 1997), was administered to all participants with the aim of determining whether they possessed an adequate level of English language understanding. Age-equivalent standardized scores were used in subsequent analyses.

Nonverbal ability and memory

The Block Design subtest from the Wechsler Preschool and Primary Scale of Intelligence–Revised (Wechsler, 2013) was used as a proxy measure of nonverbal ability, and the Digit Span subtest from the British Ability Scales II (Elliott, Smith, & McCulloch, 1996) was used to assess verbal memory. Age-equivalent standardized scores were used in all subsequent analyses.

These cognitive measures were chosen because the TimbreApp may have imposed additional memory load and required good language understanding and general cognitive ability to be performed by young children. By including these measures, we wanted to ensure that the task was measuring melodic expectations rather than other cognitive abilities.

Self-report questionnaires for parents

Parents were asked to complete (a) the Music@Home Questionnaire–Preschool (Politimou et al., 2018), an instrument that is designed to quantify musical exposure and interactions in the home environment of infants and preschoolers (Cronbach's α for Preschool version = .851) and which comprises four subscales (Parent Initiation of Musical Behavior, Child's Active Engagement With Music, Parental Beliefs About Music, and Breadth of Musical Exposure); (b) seven ad hoc items asking about the frequency of their children's musical activities outside the home; (c) the Goldsmiths Musical Sophistication Index (GOLD-MSI), a self-report instrument designed to measure musical sophistication (i.e., the capacities necessary for successfully engaging with music besides being skilled at playing a

Fig. 1. Positive and negative feedback from the TimbreApp melodic priming paradigm.

musical instrument; Cronbach's α = .926) (Müllensiefen, Gingras, Musil, & Stewart, 2014); and (d) two additional items assessing types of music their children were most frequently exposed to in the household and types of songs most frequently sung to or with their children. For both of the latter items, parents were requested to tick one or more of six types of musical styles. All children met the requirements of adequate exposure to Western music in the household (i.e., no child was frequently exposed to non-Western musical styles).

Procedure

Participants were tested across three or four sessions held on different days. Each session lasted approximately 20–30 min. The first session was designed to establish that participating children were able to perform the TimbreApp task which requires speeded responses and correct sound/image matching for each instrument (trumpet or piano). To ensure that participants could identify the piano and trumpet instruments by their sound and image, 6 trials of a timbre recognition task were first administered. In this task, children listened to a trumpet or piano sound and needed to respond by tapping on the correct instrument. If children responded correctly on 5 of the 6 trials, they moved on to the next stage that required them to complete 4 practice trials in the actual task format with a 3-of-4 correct inclusion criterion. The 40 TimbreApp trials (divided into two sets of 20 trials each, including 2 practice trials before each set) and cognitive measures were administered in the remaining two test sessions. The order of administration was held constant for all children, but the number of tasks completed in each session varied depending on each child's attention on the given day. The order of tasks was as follows: practice session for TimbreApp, screening vocabulary test (BPVS), TimbreApp Test Session 1, TimbreApp Test Session 2, Digit Span, and Block Design. Self-report questionnaires were handed out to parents/caregivers during pickup times and were returned completed to their children's classrooms.

Results

All data were analyzed using SPSS (Version 20.00) and the R software environment (R Core Team, 2012). Children's group performance in two baseline cognitive tasks assessing memory and nonverbal ability are shown in Table 2.

A series of nonparametric comparisons (Mann–Whitney) were performed between monolingual children (n = 39) and bilingual children (n = 7) to identify any differences in cognitive performance resulting from bilingualism. No statistically significant differences were found between monolingual and bilingual children in any of the tasks (vocabulary: U = 107.5, p = .37; nonverbal ability: U = 112, p = .45; verbal memory: U = 111, p = .43); thus, a single group including both monolingual and bilingual children was used for all analyses.

Effects of age on the melodic priming effect

Previous work on melodic priming in adults (Marmel & Tillmann, 2009; Omigie et al., 2012) has shown that speed of response is facilitated only for target notes/chords that have the same timbre as the preceding context (target notes played in piano). However, because this is the first study examining melodic priming in very young children, data for both timbres are presented. Descriptive statistics for accuracy of responses and RTs sorted by target type (high probability or low probability)

Table 2
Participants' performance in cognitive and language screening tasks.

Task	Scoring	Min	Max	*M*	*SD*
BPVS	*M* = 100, *SD* = 15	88	140	112.43	10.43
WPPSI-BD	Range = 1–19	7	19	12.04	3.09
Digit Span	*M* = 50, *SD* = 10	22	99	77.85	18.85

Note. Min, minimum; Max, maximum; BPVS, British Picture Vocabulary Scale; WPPSI-BD, Wechsler Preschool and Primary Scale of Intelligence–Block Design.

and target timbre (same context–piano or different context–trumpet) are presented in Table 3 and Fig. 2.

Given that developmental changes tend to occur at a rapid rate during early childhood, we first ran a preliminary analysis to explore the possibility that age has an influence on either accuracy or speed of response. To this end, two separate repeated-measures ANOVAs were carried out with accuracy and correct RTs as dependent variables. Target timbre (same context–piano or different context–trumpet) and target type (high probability or low probability) were entered as within-participants factors and age group (reception or Year 1) as a between-participants factor. This analysis yielded no significant interactions of age group with any of the other factors when all target notes were considered (accuracy: all $ps > .10$; RTs: all $ps > .10$) or when only piano target notes were considered (accuracy: age group–target type interaction $p = .702$; RTs: age group–target type interaction $p = .113$). Therefore, a single age group was used for all subsequent analyses to take advantage of the statistical power of the full sample.

Melodic priming effect

Accuracy

A 2 × 2 repeated-measures ANOVA was conducted on accuracy (the proportion of correct responses) with target timbre (same context–piano or different context–trumpet) and target type (high probability or low probability) as within-participants factors. No significant main effects or interactions were found (all $ps > .10$), demonstrating that there was no influence of either target timbre or target type on the accuracy with which children responded.

However, because our focus was on melodic priming, and previous work with adults has shown that response accuracy was greater for high-probability notes than for low-probability ones only when the target was the same timbre as the context (e.g., Omigie et al., 2012), we investigated the effects of probability when ANOVAs were run separately on piano and trumpet conditions. Therefore, two follow-up 2 × 2 repeated-measures ANOVAs with target type as a within-participants factor were run separately for target notes rendered in piano and for those rendered in trumpet.

The ANOVA for piano target notes revealed a significant effect of target type, $F(1, 45) = 7.23$, $p = .01$, $\eta^2 = .13$, with children responding more accurately to high-probability notes than to low-probability ones (see Table 3). No effect of target type was revealed in the analysis where trumpet target notes were considered, $F(1, 45) = 0.07$, $p = .785$, $\eta^2 = .00$.

Response times

Only RTs within 2 standard deviations of the mean response for each child were considered. RTs for correct trials were entered into a 2 × 2 repeated-measures ANOVA with target timbre (same context–piano or different context–trumpet) and target type (high probability or low probability) as within-participants factors. The main effect of target timbre was significant, $F(1, 45) = 5.93$, $p < .05$, $\eta^2 = .12$, indicating that children generally responded faster to trumpet target notes than to piano ones in both the high- and low-probability conditions (see Table 3 for RT means and standard deviations). This is likely to be because the trumpet timbre perceptually segregated from the preceding notes in piano timbre due to timbral effects on auditory stream segregation (Bregman, 1990). A marginally significant interaction between target timbre and target type, $F(1, 45) = 3.73$, $p = .06$, $\eta^2 = .08$, was also revealed.

Table 3
Means (and standard deviations) for accuracy of responses and response times sorted by target type and target timbre.

		High probability	Low probability
Accuracy (out of 10)	Piano	9.58 (0.61)	9.34 (0.79)
	Trumpet	9.32 (0.94)	9.36 (0.79)
Response time (ms)	Piano	950 (260)	990 (310)
	Trumpet	0.93 (0.27) 930 (270)	920 (270)

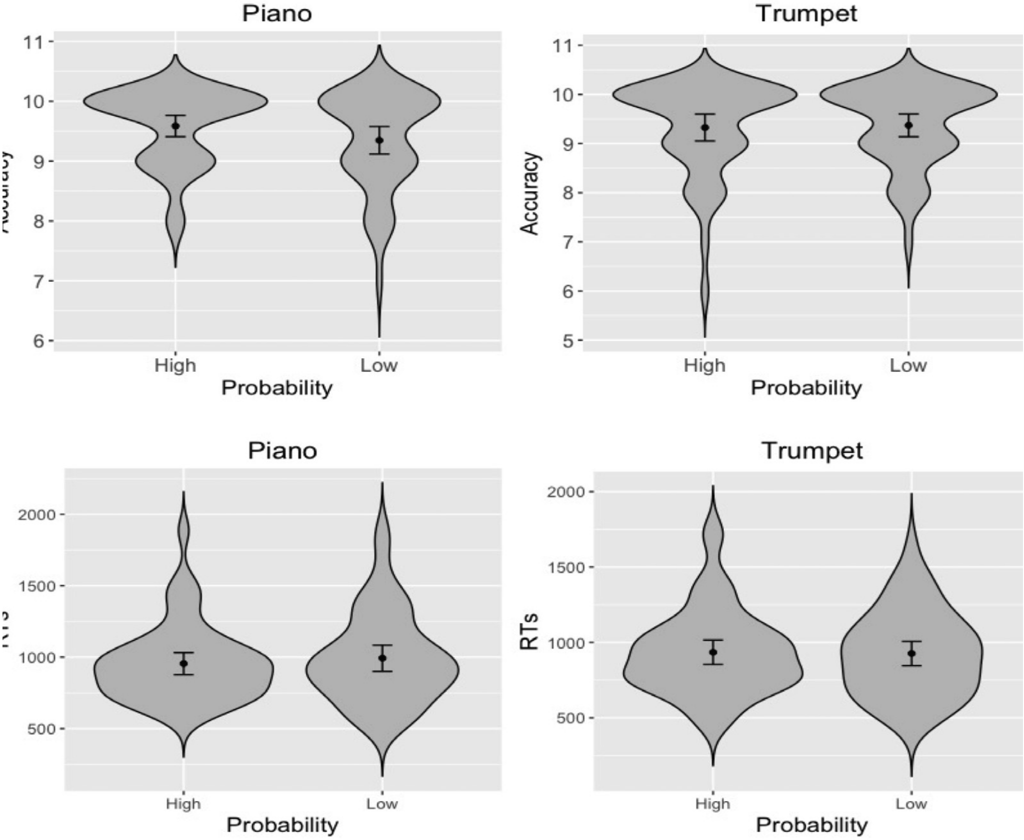

Fig. 2. Violin plots showing probability density, mean and confidence intervals for accuracy of responses and response times (RTs in ms) sorted by target type and target timbre.

To further investigate the marginally significant interaction between target timbre and target type, two follow-up repeated-measures ANOVAs with target type as a within-participants factor were carried out separately on piano and trumpet target notes. The ANOVA on piano target notes yielded a significant main effect of target type, $F(1, 45) = 4.82$, $p < .05$, $\eta^2 = .09$, demonstrating that, following the adult pattern, children responded faster to high-probability piano targets than to low-probability ones (see Table 3).

An ANOVA run on trials with trumpet target notes revealed no significant effect of target type on RTs, $F(1, 45) = 0.32$, $p = .573$, $\eta^2 = .00$. This extends findings with adults indicating that the expected priming pattern was not present when target notes were rendered in a different timbre than the preceding context (Omigie et al., 2012).

Associations among the home musical environment, cognitive abilities, and performance in the melodic priming task

Based on previous work by Omigie et al. (2012), the difference in RTs and the difference in accuracy proportions between expected and unexpected endings in correct trials where piano was the target were taken as a measure of the strength of expectations based on implicit knowledge of musical structure. To account for individual differences in average RTs and timbre discrimination ability, all score differences were transformed into *z* scores. We approached the question of whether an association exists between the strength of melodic expectations and the other variables in two ways: one by considering all the trials in the melodic priming task and a second more sensitive method where we excluded trials in which the final interval was large (i.e., the pitch jump was six or more semitones) (n = 12). As reported by Huron (2006), listeners tend to find small intervals more expected than large ones, reflecting the fact that small intervals occur more frequently in Western melodies (Huron, 2001). Large pitch jumps are likely to influence speed of response independent of learned musical knowledge associating pitches with their preceding context. For melodies ending in small intervals, on the other hand, the greatest influence on note probability is likely to be tonal stability in context, which is thought to be acquired through stylistic enculturation (Huron, 2006). Therefore, this manipulation is likely to provide a more sensitive measure of the strength of implicit expectations, acquired through exposure, via statistical learning.

Correlations were then performed among the two measures of strength of melodic expectations, Music@Home scores, number of musical activities outside the home, and cognitive abilities (nonverbal ability and verbal memory). With respect to differences in RTs and accuracy rates when considering all the trials, no significant correlations were found between strength of implicit expectations and any of the variables (see Table 4), suggesting that implicit knowledge of musical structure is formed independent of these specific cognitive abilities and experience with music as measured in the current study.

As can be seen in Table 4, bivariate correlations between differences in RTs using only trials with small pitch intervals revealed no significant associations between the strength of implicit expectations and any of the variables. However, with respect to differences in accuracy, we observed a trend toward significance between the strength of implicit expectations and global scores on the Music@Home Questionnaire (p = .093).

Correlations were then performed between the strength of expectations (i.e., differences in accuracy between high- and low-probability trials with piano endings using trials with only small pitch intervals) and all subscales of the Music@Home Questionnaire to examine whether specific associations were driving the trends toward significance. As seen in Table 5, two subscales of the Music@Home Questionnaire were significantly associated with strength of melodic expectations: Parent Initiation of Musical Behavior and Breadth of Musical Exposure. Furthermore, after controlling for parents' musical sophistication and children's musical activities outside the home, the association between strength of melodic expectations and Breadth of Musical Exposure remained significant.

Given the highly significant correlation between the Parent Initiation of Musical Behavior and Breadth of Musical Exposure subscales (r = .68, p < .001), a composite score was created to represent these two dimensions, which reflect the active role of parents in shaping the family musical environment. This composite score was then entered into a linear regression analysis to investigate predictive relationships between the home musical environment and the strength of melodic expectations

Table 4
Bivariate correlations between controlled and uncontrolled measures of strength of implicit expectations, cognitive tasks, and the home musical environment.

	RT	RT (sm)	Acc	Acc (sm)	NVA	VM	M@H	Mus Act
RT	–							
RT (sm)	.82**	–						
Acc	.11	.07	–					
Acc (sm)	.23	.15	.66**	–				
NVA	−.03	.02	−.00	−.25	–			
VM	.14	−.09	.03	.20	.22	–		
M@H	−.00	−.02	−.06	.26^{+}	−.26	.27	–	
Mus Act	−.02	−.02	−.04	−.03	.00	.39**	.49***	–

Note. RT, mean difference between response times in high- and low-probability trials with piano endings; RT (sm), mean difference between response times in high- and low-probability trials with small intervals at the end; Acc, mean difference between accuracy rates in high- and low-probability trials with piano endings; Acc (sm), mean difference between accuracy rates in high- and low-probability trials ending in small intervals; NVA, nonverbal ability; VM, verbal memory; M@H, Music@Home Questionnaire–Preschool; Mus Act, musical activities outside the home.

$^{+}$Marginally significant p value (p = .093).

$^{**}p$ < .01.

$^{***}p$ < .001.

Table 5
Bivariate and partial correlations between strength of implicit expectations (accuracy) and the subscales of the Music@Home Questionnaire–Preschool.

Music@Home Questionnaire–Preschool subscale	Difference in acc (sm)	Controlling for Gold-MSI and Mus Act
Parental beliefs	.23	.15
Child's active engagement	. 02	−.02
Parent initiation of musical behavior	.31*	.26
Breadth of musical exposure	.32*	.35*

Note. Difference in acc (sm), mean difference between accuracy rates in high- and low-probability trials with small intervals at the end; Gold-MSI, Goldsmiths Musical Sophistication Index of parent; Mus Act, child's musical activities outside the home.
$^{*}p < .05$.

Table 6
Summary of Models 1, 2, and 3 predicting strength of melodic expectations.

	β	t	p	R^2	AIC	F	p
Model 1				.10	−9.11	5.55	<.05
Comp score	.34	2.35	<.05				
Model 2				.10	−7.15	3.22	.05
Comp score	.43	2.52	<.05				
Mus Act	−.23	−1.36	.18				
Model 3				.07	−5.17	2.10	.11
Comp score	.42	2.21	<.05				
Mus Act	−.23	−1.30	.18				
Gold-MSI	.02	.130	.89				

Note. AIC, Akaike Information Criterion; Comp score, composite score of the Parent Initiation of Musical Behavior and Breadth of Musical Exposure subscales of the Music@Home Questionnaire; Mus Act, musical activities outside the home; Gold-MSI, Goldsmiths Musical Sophistication Index.

(measured by differences in accuracy rates in high- and low-probability trials ending in small intervals). Parents' musical sophistication and children's musical activities outside the home were also entered as predictors to explore whether they contribute to the variance in strength of melodic expectations. The *drop1()* function in R was used to gradually eliminate variables (backward elimination) with no significant contribution to the model. As seen in Table 6, Model 1, where a composite score of the two subscales of the Music@Home Questionnaire (Parent Initiation of Musical Behavior and Breadth of Musical Exposure) is the only predictor, is the most parsimonious one and explains a notable amount of variance in strength of melodic expectations.

Discussion

The first aim of this study was to investigate 5- and 6-year-old children's implicit knowledge and processing of Western melodic structure. To this end, a novel musical task was used to probe melodic priming. Faster RTs and higher accuracy rates for high-probability ending notes rendered in the same timbre as the context were taken as evidence that the children have already formed melodic expectations reflecting their knowledge about which notes are more likely to follow others in a melody.

Our results confirm that young children aged 5 and 6 years can already process Western melodies in an adult-like manner, corroborating the notion that implicit musical learning emerges from informal exposure to a given musical culture and that melodic expectations can reflect this type of learning in children (Bigand & Poulin-Charronnat, 2006; Tillmann, 2005). Crucially, our results showed that age did not have an effect on performance (either when accuracy or when RTs were considered), suggesting that processing of melodic structures may already be robust by 5 years of age. Furthermore, cognitive variables such as memory and verbal ability were not associated with the strength of implicit expectations, suggesting that (a) performance in the priming task was not driven by underlying cognitive abilities (i.e., the task was easy to understand and not too difficult for young children to perform) and (b) internalization of musical structural regularities might not depend on general cognitive abilities.

Specifically, during our task, children responded with greater accuracy to high-probability notes relative to low-probability ones. Furthermore, children showed faster RTs when identifying high-probability notes relative to low-probability ones. These findings are contextualized when considering previous research in harmonic priming in preschool children (Marin, 2009), which revealed priming effects in RTs but not in accuracy rates. It is important to note, however, that this study used chord progressions specifically composed for the experiment to manipulate harmonic expectations. In contrast, the current study investigated priming effects in melodic sequences selected from an existing database of folk tunes, thereby providing a closer simulation of everyday musical exposure.

Although priming effects are typically assessed in terms of RTs, they have also been observed in terms of higher accuracy rates for expected versus unexpected stimuli in adults (e.g., Bharucha & Stoeckig, 1986). Indeed, our results are broadly in agreement with previous research on melodic priming effects in adults (Marmel et al., 2008, 2010; Omigie et al., 2012; Tillman, 2005; Tillmann et al., 2006), demonstrating that highly expected target notes and chords facilitate individuals' speed and accuracy of response. Notably, an experiment exploring melodic expectations in individuals with congenital amusia and typical controls that made use of the same computational model (i.e., IDyOM; Pearce, 2005) to select high- and low-probability targets also reported priming effects for both RTs and accuracy (Omigie et al., 2012).

With regard to children's melodic expectations, Schellenberg et al. (2002) showed that 7- to 11--year-old children's expectancy ratings conformed to the principle of pitch proximity (an expectation for small intervals) but not to that of pitch reversal (an expectation for large intervals), whereas adults' expectations showed evidence of both principles. We showed that 5- and 6-year-old children show melodic expectations that conform to stylistic probabilities of continuation for both large and small intervals. There is a key difference between this work and the current study in that, the use of an explicit task in Schellenberg et al. (2002) may have masked children's actual level of implicit knowledge.). It is important to note, that when 5-year-old children in the above study were tested with a task which required them to sing continuations of short melodies (a task that was less constrained), their sung tones conformed to both principles of pitch proximity and pitch reversal, consistent with our findings. However, all 5-year-olds in that sample (n = 15) were prescreened and selected on the basis of their high musical aptitude and sophistication compared with peers. Therefore, the results, although very informative, might not generalize to a broader population. On the other hand, the sample in the current study consisted of 46 children with various levels of engagement in musical activities outside the home that were not associated with the strength of their melodic expectations.

Other studies looking at music structural processing in young children have explored sensitivity to violations in the key or harmony of melodies and chord progressions. When tested with electroencephalography (EEG), children aged 4, 3.5, and even 2 years showed early event-related potential (ERP) responses to out-of-key and out-of-harmony irregular chords of similar latency and scalp distribution as in studies with older children (Corrigall & Trainor, 2014, 2019; Jentschke, Friederici, & Koelsch, 2014). This was taken as evidence of sensitivity to chords that violate either the key or harmony of a sequence (Corrigall & Trainor, 2014). Notably, this sensitivity was not present in the neural responses of 4-year-old children when tested with melodic sequences lacking a chord accompaniment (Corrigall & Trainor, 2014). On the other hand, 5-year-old children were sensitive to key violations but not harmony violations when asked to make explicit evaluative judgments for melodies lacking an underlying chord progression (Corrigall & Trainor, 2014). Similarly, Trainor and Trehub (1994) demonstrated that 7-year-old children, but not 5-year-old children, were able to detect a note that violated the implied harmony of the melody. Overall, the above studies have provided considerable insight with respect to how young children's music structural processing progresses from key membership to awareness of harmony, suggesting that 5 years of age may be a critical transition zone. However, they have not yet provided conclusive evidence with respect to the processing of melodies where the harmony is implied. In our study, we focused on this aspect by using the IDyOM model to simulate cognitive processes underlying musical expectations in melodies.

The second aim of this study was to explore associations between the strength of melodic expectations and the home musical environment. For both RTs and accuracy measures, we used two different measures to index the strength of implicit expectations: first, the mean difference (in RT or accuracy proportion) for expected versus unexpected piano endings including all trials and, second, a more sensitive measure that was similar to the first except that all trials with large pitch jumps at the end of the melodies were excluded (Huron, 2006). Results showed no associations between the first measure and Music@Home scores. When using the second more sensitive measure, the association between the Music@Home Questionnaire and strength of melodic expectations, as reflected in accuracy rates but not RTs, showed a trend toward significance. To further examine this trend, the links between strength of melodic expectations and individual subscales of the Music@Home Questionnaire were explored. This analysis revealed moderate but significant relations between the strength of melodic expectations and two subscales: Parent Initiation of Musical Behavior and Breadth of Musical Exposure. Furthermore, a composite score for these two subscales of the Music@Home Questionnaire significantly predicted strength of melodic expectations after accounting for musical sophistication of the parents and the children's musical activities outside the home. Both these subscales highlight the role of caregivers as active agents in the shaping of children's musical environment. Given that these results are somewhat exploratory, it is important to follow up in the future with confirmatory experimental research including deliberate manipulations of breadth of musical exposure and quantity of parent–child musical interactions.

Taken together, the above findings add to our knowledge regarding music perception during the early years in two ways by suggesting, first, that the internalization of regularities may indeed be a crucial mechanism for implicit musical learning and, second, that melodic expectations may be influenced by the amount of exposure to relevant stimuli. Indeed, statistical learning may underlie the acquisition of structure in music, as demonstrated in experiments manipulating the distributional properties of tonal material (Jonaitis & Saffran, 2009; Saffran, Johnson, Aslin, & Newport, 1999). In these experiments both adults and children exhibited sensitivity to statistical properties of auditory tone sequences and stored this information in memory. These findings also complement previous studies, which have shown that participation in musical interventions can enhance sensitivity to culturally specific features of music (Gerry et al., 2010, 2012) as well as sensitivity to complex temporal structures in music (that are nevertheless of Western origin) in infants younger than 12 months (Zhao & Kuhl, 2016). It is important to note, however, that infants in the above studies were assigned to formally structured musical interventions as opposed to the informal family environment measured in the current study.

These two possibilities draw interesting parallels between the acquisition of music and other highly structured systems such as language. Several studies have shown that infants, children, and adults are sensitive to statistical distributions in speech that are relevant to different aspects of language learning. For instance, (Saffran, 2002) showed that both school-aged children and adults rely on statistical information in the sequencing of words (i.e., Type A words always preceding Type B words) to learn an artificial grammar, whereas other evidence has shown that infants as young as 6–8 months track statistical distributions of sounds in continuous speech to extract phonetic categories (6- and 8-month-olds: Maye, Werker, & Gerken, 2002) and sequences of syllables (8-month-olds: (Saffran et al., 1996)). Interestingly, music and language follow similar developmental trajectories, and statistical learning of auditory information has been proposed to be a critical mechanism underlying the acquisition of structure in both modalities (Brandt, Slevc, & Gebrian, 2012; François, Chobert, Besson, & Schön, 2013; Politimou, Dalla Bella, Farrugia, & Franco, 2019). Based on this account, François et al. (2013, 2017) have demonstrated that musical input in the form of either musical training (8-year-old children) or sung melodies (neonates) can positively influence the segmentation of streams of speech into words, presumably because it facilitates the extraction of statistical regularities. Furthermore, a wealth of studies has indicated that language acquisition is heavily influenced by the amount and quality of language input during the early years (e.g., Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Rowe & Goldin-Meadow, 2009; Weisleder & Fernald, 2013). Therefore, an account in which the acquisition of musical structure is influenced by the family's musical environment and exposure to one's native musical system seems plausible, and the current results provide additional support for this account.

In summary, our findings show that children as young as 5 years process Western melodic structures to form melodic expectations, using a similar experimental approach as in adult studies. The results also show that the use of the IDyOM model in generating the stimuli for the melodic priming task can provide a sensitive probe of implicit musical knowledge. Furthermore, aspects of the musical home environment such as breadth of musical exposure showed moderate but significant associations with strength of implicit expectations even after accounting for parents' musical sophistication and musical activities outside the home. Future studies should further explore the developmental trajectory of the formation of melodic expectations and identify the age at which children first start being sensitive to the melodic structures of their native musical system, as well as probing the types of musical experiences that may influence individual differences in sensitivity to melodic expectations.

CRediT authorship contribution statement

Nina Politimou: Conceptualization, Methodology, Investigation, Formal analysis, Project administration, Writing - original draft. **Pedro Douglass-Kirk:** Software, Writing - review & editing. **Marcus Pearce:** Conceptualization, Methodology, Software, Writing - review & editing. **Lauren Stewart:** Conceptualization, Methodology, Writing - review & editing. **Fabia Franco:** Conceptualization, Methodology, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

Nina Politimou was responsible for conceptualization, methodology, investigation, formal analysis, project administration, and writing–original draft. Pedro Douglass-Kirk was responsible for software and writing–review and editing. Marcus Pearce was responsible for conceptualization, methodology, software, and writing–review and editing. Lauren Stewart was responsible for conceptualization, methodology, and writing–review and editing. Fabia Franco was responsible for conceptualization, methodology, writing–review and editing, and supervision.

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