Developmental changes in the perception of pitch contour: Distinguishing up from down

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Musically untrained participants in five age groups (5-, 6-, 8-, and 11-year-olds, and adults) heard sequences of three 1 s piano tones in which the first and third tones were identical (A5, or 880 Hz) but the middle tone was displaced upward or downward in pitch. Their task was to identify whether the middle tone was higher or lower than the other two tones. In experiment 1, 5-year-olds successfully identified upward and downward shifts of 4, 2, 1, 0.5, and 0.3 semitones. In experiment 2, older children (6-, 8-, and 11-year-olds) and adults successfully identified the same shifts as well as a smaller shift (0.1 semitone). For all age groups, performance accuracy decreased as the size of the shift decreased. Performance improved from 5 to 8 years of age, reaching adult levels at 8 years. © *2008 Acoustical Society of America.* [DOI: 10.1121/1.2956470]

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I. INTRODUCTION

Subtle pitch changes play a critically important role in music. Melodies typically move in small steps, most commonly by one or two semitones (Vos and Troost, 1989). Moreover, major chords and harmonies, which signal positive emotions, differ by one semitone from minor chords and harmonies, which signal negative emotions (e.g., Gagnon and Peretz, 2003; Hunter *et al.*, 2008). Musically untrained listeners often notice pitch deviations that are smaller than one semitone, such as when a performer sings out of tune.

Distinguishing one pitch from another is less difficult than identifying one pitch as being higher or lower than another (Cooper, 1994; Johnsrude *et al.*, 2000; Sergeant and Boyle, 1980). The pitch contour of a melody—its pattern of successive changes in pitch direction (same, up, down)—is perceptually salient for listeners of all ages and levels of musical experience (for reviews see Dowling, 1994; Thompson and Schellenberg, 2006; Trehub, 2000). At times, infants fail to respond to transpositions of a relatively unfamiliar melody (i.e., change in pitch level, with contour and intervals preserved, Chang and Trehub, 1977; Trehub *et al.*, 1984), but they respond reliably to changes in its pitch contour (Trehub *et al.*, 1984), even when the directional changes are restricted to a single note (Trehub *et al.*, 1985). Although melodic contour is central to music perception regardless of age (e.g., Dowling, 1994; Trehub, 2000), little is known about the developmental course of contour processing. Frequency resolution is thought to be mature by about 8 years of age (Cooper, 1994; Maxon and Hochberg, 1982; Thompson *et al.*, 1999), but it is unclear whether progress in identifying directional changes in pitch follows a similar timeline.

Young children seem to have particular difficulty understanding concepts such as *high* and *low* (or *up* and *down*) in relation to pitch. Andrews and Madeira (1977) found, for example, that 6- and 7-year-olds could learn to associate a pitch of 262 Hz with a large pig and a pitch of 523 Hz with a small pig, but they were unable to designate the pitches as high or low (or *higher* or *lower*). By contrast, Jeffrey (1958) found that 5-year-olds had difficulty linking contrasting pitches with left and right button presses, which implies that 6-year-olds' successful acquisition of relations between pitch level and animal size (Andrews and Madeira, 1977) may have been facilitated by real world experience. Costa-Giomi and Descombes (1996) contend that 6-year-olds' difficulty identifying pitch direction is attributable, in part, to the multiple meanings of the terms high and low in English. When they trained French-speaking 6-year-olds to label pitches with the terms *aigu* and *grave*, which are used exclusively for high and low pitch, or *haut* or *bas*, which have multiple meanings (corresponding to the English terms high and low), children trained with the single-meaning terms were more accurate in labeling pitches separated by two octaves than were children trained on the multiple-meaning terms.

Although 6-year-olds readily discriminate ascending from descending pitch patterns, and they can match the patterns instrumentally, they do not spontaneously use the terms up, down, high, or low when referring to the patterns (Hair, 1977). With extensive training over the course of six days, Soderquist and Moore (1970) found, however, that 5-, 7-, and 9-year-olds improved substantially in their ability to identify the pitch direction of two pure tones (sine waves) differing in pitch. The minimal pitch difference required for correctly judging pitch direction was smallest for 9-year-olds and largest for 5-year-olds, who also showed the greatest benefit from training. It is possible, however, that children would achieve comparable or greater success without such extensive training in the context of stimuli with greater ecological validity.

The goals of the present study were twofold. Because of contradictory findings regarding 5-year-olds' ability to identify pitch direction (Van Zee, 1976; Soderquist and Moore, 1970), it was of interest to examine this ability in the context of ecologically valid stimuli (piano tones) and an age-appropriate task. The second goal was to examine age-

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related changes in the ability to identify directional changes in pitch. As noted, identifying directional changes in pitch is more difficult than differentiating pitches even though the former skill depends critically on the latter skill. As the frequency difference between two tones becomes smaller, one would expect tone differentiation to become more effortful (i.e., involving more cognitive resources), with negative consequences for the more challenging pitch direction task. In other words, identifying pitch direction should get progressively more difficult as the frequency difference between tones decreases. Moreover, one would expect the identification of pitch direction to be more difficult for listeners with immature frequency resolution than for those with mature frequency resolution. Because 8-year-olds are thought to be adultlike in terms of frequency resolution (Cooper, 1994; Maxon and Hochberg, 1982; Thompson *et al.*, 1999), they were expected to perform as accurately as adults at identifying pitch direction. Younger children were expected to perform more poorly because of their poorer frequency resolution and their poorer understanding of relational concepts (Andrews and Madeira, 1977; Hair, 1977; Jeffrey, 1958).

On the basis of well-documented individual differences in pitch resolution, even in musical contexts (Drayna *et al.*, 2001), individual differences in proficiency were anticipated at all age levels. Finally, because musical training enhances the ability to identify directional changes in pitch (e.g., Sergeant, 1973), participation was limited to those without musical training.

II. EXPERIMENT 1

A. Method

1. Participants

Twenty-six 5-year-olds (13 boys, 13 girls) were recruited from the local community. None had taken music lessons, and none had a personal or family history of hearing problems. Each child received a token gift for their participation. An additional two children were tested but excluded from the sample because they did not complete the entire testing session.

2. Apparatus and stimuli

Testing was conducted in a double-walled sound-attenuating booth (Industrial Acoustics Co.). Stimulus presentation and responses were controlled by a Dell personal computer with software created in REALBASIC via a Harman/Kardon 3380 amplifier and Electro-Medical Instrument Co. loudspeakers. The stimuli were presented at a comfortable volume.

The stimuli were modeled after those used to study adults with impaired pitch and music perception (Hyde and Peretz, 2004). A set of 11 tones was synthesized using *The Grand* (a piano timbre) and CUBASE software. The set included one standard tone with a fundamental frequency of 880 Hz, as well as five higher and five lower tones displaced in pitch by 4, 2, 1, 0.5, and 0.3 semitones upward and downward from the standard. Individual tones were 1 s in duration with a natural piano onset (i.e., rapid and slightly percussive) and a 10 ms decay. They were combined using SOUNDEDIT software into sequences of three tones. In each sequence, the first and third tones were standards, and the second tone was higher or lower than the standard. Thus, the stimulus set comprised ten different three-tone sequences, each 3 s in duration. To eliminate potential amplitude cues to pitch level (Grau and Kemler-Nelson, 1988; Neuhoff *et al.*, 2002; Neuhoff *et al.*, 1999), the amplitude of the three tones in each sequence was varied subtly and at random. Specifically, one tone was normalized at 94% of maximum amplitude, another at 97%, and the third at 100%.

3. Procedure

Children were first familiarized with the testing booth and told that they would be playing a game. The game involved hearing three sounds in a row and deciding if the second sound went up or down. To facilitate understanding of the two-alternative forced-choice (2AFC) task, the experimenter explained the relevant distinction in a number of ways, providing graphic as well as vocal examples. Included in this explanation was an animation of a ball rising or falling in synchrony with rising or falling pitch (by four semitones) to provide a visual analog of the task. Participants completed six training trials that included the animated "bouncing" ball. The children then completed six practice trials with the four-semitone change but no visual aid.

The test trials were presented in five blocks, beginning with the largest pitch change (four semitones) on the first block and proceeding through successively more difficult levels to the smallest change (0.3 semitones). Twelve trials were completed in each block, with the direction of the pitch change (i.e., up or down) determined randomly on each trial, constrained so that middle tone was higher than the first and third tones on six trials but lower on the other six. A flashing star was provided as feedback for correct answers. Stickers were given to the children at the end of each block to maintain their interest in the task.

B. Results and discussion

Preliminary analyses revealed that gender did not influence performance or interact with the difficulty of the testing block, either in the present experiment or in experiment 2. Gender was not considered further. On the training trials with a visual cue accompanying the pitch changes, 5-year-olds were near perfect (95% correct) in distinguishing up from down ($M=5.69$ correct out of 6 trials, $\mathrm{SD}=0.62$). Performance on the six practice trials was considerably more variable, averaging 75% correct ($M=4.50$, $\mathrm{SD}=1.48$), although 20 of the 26 children had at least four correct. Children's performance on test trials was compared with chance levels (50%, 6 out of 12 correct) by means of one-sample t-tests for each of the five blocks. Performance exceeded chance levels for each block, $ps<0.01$, with the mean exceeding 60% correct in each case and 80% correct on the first (easiest) block. A repeated-measures analysis of variance (ANOVA) confirmed that performance varied across blocks, $F(4,100)=9.64$, $p<0.001$. As shown in Fig. 1, performance decreased monotonically across blocks as the task became more difficult.

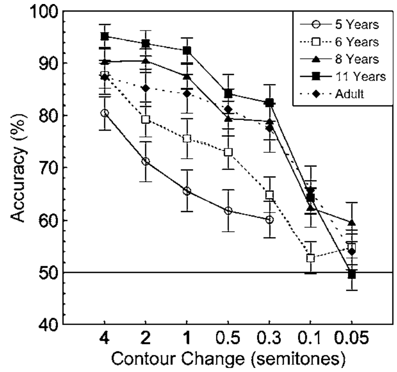

FIG. 1. Mean accuracy scores and standard errors for each age group and condition. In experiment 1, 5-year-olds were tested in five conditions. In experiment 2, older children (6-, 8-, and 11-year-olds) and adults were tested in seven conditions.

Also of interest was whether individual children performed at above-chance levels ($\alpha=0.05$, binomial test), corresponding to 9 or more correct responses out of 12 trials (75% correct). The results are summarized in Table I. Even with this conservative criterion, significantly more than half of the 5-year-olds (69%, or 18/26) succeeded in the four-semitone block, $\chi^2(1,N=26)=3.85$, $p<0.05$, which provides conclusive evidence that 5-year-olds can map the terms up and down onto changes in pitch. In each of the more difficult blocks, less than half of the children met this performance criterion.

Finally, because descending pitch changes are more frequent than ascending changes in actual music (Vos and Troost, 1989), the possibility of biased responding was investigated. One-sample *t*-tests were used to determine whether the number of up responses differed significantly from 6 (i.e., 50% up responses, 50% down responses), separately for each of the five blocks. There was no evidence of such a bias, with the proportion of up responses varying minimally from 50% across blocks (i.e., from 48% to 52%).

III. EXPERIMENT 2

A. Method

1. Participants

The sample included 29 6-year-olds (17 boys, 12 girls), 30 8-year-olds (13 boys, 17 girls), 30 11-year-olds (20 boys, 10 girls), and 29 young adults (10 men, 19 women). One additional 6-year-old was recruited but failed to complete the test session. No participant had formal music lessons or hearing problems. As in experiment 1, the children were recruited from the local community and received a token gift. The adults were university students who received either partial course credit or token remuneration.

2. Apparatus and stimuli

The apparatus and stimuli were identical to those from experiment 1 except that there were four additional tone sequences with more subtle changes in pitch to the middle tone. The middle tone of these additional sequences was displaced upward and downward from the standard tone by 0.1 and 0.05 semitones.

3. Procedure

For the children, the procedure was identical to experiment 1 except that (1) only the 6-year-olds played with stickers between blocks of trials, and (2) two additional, more difficult blocks of trials were added to the test session so that there were seven blocks of test trials rather than five. As in experiment 1, trials were presented in blocks, with successive blocks increasing in difficulty from the easiest block (4 semitones) to the most difficult block (0.05 semitones).

The procedure differed slightly for adults, who were told simply that they would be listening to a number of sequences, each containing three tones, and that their task was to decide on each trial whether the second tone was higher or lower in pitch than the first and third tones by selecting the appropriate option on a computer touch screen. To clarify the distinction between higher and lower, a number of three-tone vocal examples with higher and lower middle tones were provided. Feedback (correct or incorrect) was provided after each test trial.

B. Results and discussion

As with the 5-year-olds in experiment 1, children in the present experiment had no problem distinguishing up from down when pitch changes were accompanied by a visual cue. Performances were 98%, 99%, and 100% correct for the 6-, 8-, and 11-year-olds, respectively. Mean levels of performance on the practice trials with no visual cues exceeded 86% correct (better than five out of six correct) for each

TABLE I. Percentage of participants performing significantly better than chance (i.e., 9 or more correct out of 12) in each testing block. Five-year-olds (experiment 1) were tested only in the first five blocks. The seventh, most difficult block (experiment 2), is excluded because group performance did not exceed chance levels for any age group.

	Experiment 1	Experiment 2			
Block	5-year-olds	6-year-olds	8-year-olds	11-year-olds	Adults
4 ST	69.2	86.2	93.3	96.7	82.8
2 ST	46.2	69.0	90.0	96.7	82.8
1 ST	26.9	65.5	83.3	93.3	79.3
0.5 ST	38.5	55.2	70.0	76.7	72.4
0.3 ST	34.6	41.4	63.3	80.0	62.1
0.1 ST	⋯	13.8	33.3	33.3	51.7

group of children. For the test trials, separate one-sample *t*-tests for each of the four age groups and each of the seven blocks were used to compare performance with chance levels of responding (Bonferroni corrected for four tests for each block). Descriptive statistics are illustrated in Fig. 1. As expected from the results of experiment 1, older participants exceeded chance levels for the first five (easiest) blocks, $ps < 0.001$, with mean levels of performance exceeding 65% correct for each age group in each block. Indeed, for the 8-year-olds, 11-year-olds, and adults, the means exceeded 78% correct for each block. For the more difficult, 0.1-semitone condition, the three older age groups (8-year-olds, 11-year-olds, and adults) exceeded chance levels, $ps < 0.0125$, but the 6-year-olds did not. In the most difficult, 0.05-semitone condition, all four age groups performed at chance levels (i.e., <60% correct). In short, the seven testing conditions encompassed a range of difficulty that reached and surpassed the limits of participants' abilities.

Differences among age groups (four levels) and blocks (six levels) were analyzed with a mixed-design ANOVA. The final, most difficult block (0.05 semitones) was excluded from the analysis because of the floor effect observed across age groups. The analysis revealed main effects of age, $F(3,114)=4.79$, $p<0.005$, and block, $F(5,570)=80.62$, $p < 0.001$, but no two-way interaction, $p>0.2$. As shown in Fig. 1, the age effect stemmed from poorer performance for the 6-year-olds compared to the other age groups. Indeed, when the 6-year-olds were excluded from the analysis, the effect of age disappeared, $p>0.3$. The main effect of block stemmed from monotonic decreases in performance across blocks, which were evident across age groups. The single exception was the slight increase in performance among 8-year-olds from the four-semitone to the two-semitone block, although performance was virtually at ceiling (>90% correct) in both blocks.

The present sample of 6-year-olds was compared to the 5-year-olds from experiment 1 with a mixed-design ANOVA with one between-subjects factor (age: two levels) and one within-subjects factor (block: five levels, the same blocks completed by both age groups). The results revealed a main effect of age, $F(1,53)=4.67$, $p<0.05$; 6-year-olds outperformed 5-year-olds. There was also a main effect of block, $F(4,212)=22.08$, $p<0.001$, with performance decreasing monotonically for both groups as the task became more difficult, but no interaction between age and block, $F<1$.

As in experiment 1, individual performance was evaluated against chance levels for each condition. The results, summarized in Table I, reveal monotonic decreases in the number of participants succeeding as the task increased in difficulty, the sole exception involving the transition from the 0.5-to 0.3-semitone block for 11-year-olds. In other words, group decrements in performance were paralleled by decreasing numbers of individuals who met the performance criterion. Even when the majority of participants succeeded at the task, others performed relatively poorly, highlighting marked individual differences in a basic aspect of pitch perception.

Finally, the possibility of a response bias was examined by comparing the number of up responses to unbiased responding (50% up responses), separately for each age group and trial block (Bonferroni corrected for four tests for each block). As with the 5-year-olds in experiment 1, there was no evidence that listeners of any age were biased to respond up or down.

IV. DISCUSSION

The results indicate that 5-year-olds can identify directional changes in pitch, which is consistent with the findings of Soderquist and Moore (1970) but inconsistent with those of others (Jeffrey, 1958; Van Zee, 1976). The present findings differ from those of Soderquist and Moore (1970) in revealing successful pitch-direction identification after mere minutes rather than hours of training. Five-year-olds' lesser success in the previous study may be attributed to the use of pure tones rather than piano tones, the use of two-tone rather than three-tone patterns, and the absence of feedback during testing. The importance of feedback can be seen in the improvement that was evident from the practice trials (mean of 75% correct) to the first block of test trials (mean of 80% correct), which featured the same stimuli. Feedback is particularly important for 5-year-olds, who often have difficulty generalizing from training stimuli to test stimuli. For example, 5-year-old children who are trained to respond to piano tones separated by three octaves as high and low fail to transfer that training to piano tones separated by seven semitones (Jeffrey, 1958).

As can be seen in Fig. 1, all age groups performed above chance levels in the easiest condition (a 4-semitone change) and below chance levels in the most difficult condition (a 0.05-semitone change). As with other auditory abilities (e.g., frequency resolution: Allen *et al.*, 1989; auditory thresholds: Leninhan *et al.*, 1971; pitch discrimination: Cooper, 1994; Maxon and Hochberg, 1982; Thompson *et al.*, 1999), gradual, age-related improvement was apparent. Specifically, 5-year-olds performed more poorly than all other age groups, and 6-year-olds performed more poorly than older children. Nevertheless, 5- and 6-year-olds children identified the direction of pitch changes for differences as small as three-tenths of a semitone. By 8 years of age, children succeeded in identifying changes of one-tenth of a semitone.

What accounts for the precocious abilities observed in the current study in contrast to children's reported difficulty mapping the terms high and low, higher and lower, or up and down onto the dimension of pitch (Andrews and Madeira, 1977; Flowers and Costa-Giomi, 1991; Hair, 1977; Van Zee, 1976)? In addition to the use of ecologically valid stimuli and feedback, as noted above, instructions in the present study were simpler than those in some previous studies. For example, Hair (1977, p. 200) required first graders to determine whether "the sounds in the first group" (an ascending or descending sequence of five resonator bells) "move in the same way" as "the sounds in the second group." The children were instructed, further, to "mark the green word 'yes' on your paper" if the sounds move in the same way and to "mark the red word 'no' on your paper" if the sounds do not move in the same way. "Otherwise, mark the question mark." Even if first graders could comprehend the concepts up and down in relation to pitch, they would likely be confused by these instructions, especially in the absence of feedback. Interestingly, children who failed to identify the correct pitch direction succeeded in duplicating the ascending and descending sequences on the resonator bells.

As predicted, 8-year-olds' performance did not differ from that of adults, which is consistent with suggestions of mature pitch resolution by 8 years of age (Cooper, 1994; Maxon and Hochberg, 1982; Thompson *et al.*, 1999). Presumably, younger children's difficulty with pitch differentiation added to their cognitive load, exacerbating their difficulties on the pitch-direction task. The random variations in amplitude, however subtle, may have increased task difficulty for 5- and 6-year-olds, whose performance is often affected adversely by variations in an irrelevant stimulus dimension (Bialystok and Niccols, 1989). In fact, a number of researchers have reported that young children erroneously use terms associated with loudness when describing the pitch differences between paired tones (Andrews and Diehl, 1970; Hair, 1981; Van Zee, 1976). Finally, it is possible that the terms high and low, with their multiple meanings, increased task difficulty for the 5- and 6-year-olds (Costa-Giomi and Descombes, 1996). Regardless of the perceptual and cognitive factors that depressed performance in 5- and 6-year-olds, the fact remains that they succeeded in identifying the direction of pitch change at better than chance levels, even for pitch changes smaller than a semitone.

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