Learning Absolute Pitch by Children: A Cross-sectional Study

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This study is an attempt to depict the learning process of AP in Japanese children in a cross-sectional design. In this study, 104 children of 4 to 10 years of age in a music school were tested. The children had been trained within a music education system of the school since they entered the school at the age of 4. They had received a one-hour keyboard lesson a week in school and probably had everyday practice at home. The training during the initial 2-year course emphasized imitative singing with syllables in the fixed-do system while playing on the keyboard at the same time. In this training, particular emphasis was placed on establishing associations between pitches and solfège labels. In the AP test, test tones presented to the children ranged from C3 (131 Hz) to B5 (988 Hz). Children were instructed to name each tone out loud as rapidly as possible. The test score markedly increased for a fairly good number of the children with remarkable improvement from the age of 4 to 7. Children seemed to learn pitches in order of their appearance in music lessons; first, white-key notes, then black-key notes. However, one should be cautious about concluding from the present results that anyone can learn to develop AP with appropriate training, because there may be confounding factors (e.g., sampling bias and a certain dropout rate). Nevertheless, the present results are consistent with the early-learning theory of AP, and may explain the existence of partial AP (greater accuracy for white-key notes) and a high prevalence of AP in Japan.

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Among music-related abilities, absolute pitch (AP) has aroused the continuing interest of musicians and researchers who have been engaged in psychology of music. The earliest scientific description of AP appeared in volumes on psychoacoustics by Stumpf (1883). Since then, various aspects of AP have been investigated by a number of researchers (e.g., Abraham, 1901; Wellek, 1938; for reviews, see Takeuchi & Hulse, 1993; Ward, 1999). AP is believed to be a remarkable ability in that AP listeners are able to name very accurately and quickly the musical pitch of isolated tones presented in the absence of musical pitch context, in marked contrast to most other people who are unable to identify musical pitch unless some reference pitch is provided.

One of the issues AP researchers have focused on is how many people among the general population or among musicians have this remarkable ability. There is a common belief that AP is an extremely rare phenomenon, and several researchers have documented this belief. The proportion of AP possessors is roughly estimated to be less than one to 1,500 (Profita & Bidder, 1988) or even one to 10,000 (Bachem, 1955) in the general population, although it is not known whether these estimates are based on empirical data. AP is not as rare among musicians. The estimated proportion of AP possessors among musicians varies, for example, from 3.4% (Révész, 1953), 8.8% (Wellek, 1963), to about 15% (Baharloo, Johnston, Service, Gitschier, & Freimer, 1998), the estimate probably depending on the differences in criteria of AP and in samples.

There is additional evidence that AP is not so rare among music students, at least in some cultures. In a previous series of experiments (Miyazaki, 1993, 1995), university students majoring in music education (not in the course aiming at training professional musicians) were given an AP screening test, in which 60 piano tones over 5 octaves were presented. Roughly 30% of the participants scored more than 90% correct on the test and may be considered accurate AP possessors. The proportion of accurate AP possessors should be even higher among to-be-professional music students.

Another controversial issue on AP has been whether AP is learned through appropriate training. Several
investigators gave child or adult participants extensive training on pitch naming and observed improvements in their accuracy (e.g., Brady, 1970; Cohen & Baird, 1990; Crozier, 1997; Cuddy, 1968, 1970; Meyer, 1899; Mull, 1925; Russo, Windell, & Cuddy, 2003). However, the outcomes do not provide strong evidence for the learnability of AP. Some participants achieved a significant improvement in pitch naming, but did not reach the perfect or near perfect level of genuine AP possessors. Several studies demonstrated marked improvements in identifying a single tone, but it should be noted that the long-term memory of a single pitch is only a first-step toward achieving genuine AP.

Despite lacking direct empirical evidence that strongly supports the learnability of AP, there is a rich body of literature suggesting that the possession of AP is associated with early music training (for reviews, see Takeuchi & Hulse, 1993, and Ward, 1999). For example, Sergeant (1969) obtained the results of a questionnaire survey suggesting a correlation between AP possession and early music training; more self-reported AP possessors had commenced earlier music training. Miyazaki (1988) found that all his listeners who were classified as accurate AP possessors according to the AP screening test reported that they had begun piano lessons as early as ages of 3 to 5. Takeuchi & Hulse (1991) reported that, of their 19 listeners qualified as having AP by a screening test, 12 had begun music training between 3 and 6 years. Furthermore, Baharloo, Service, Risch, Gitschier, & Freimer (2000) indicated that virtually all of participants who exhibited the most clear-cut AP had had music training by the age of 6. More recently, Brown, Sachs, Cammuso, & Folstein (2002) reported the existence of AP possessors without early music training, counterevidence allegedly challenging the early-learning view of AP. However, this argument is not fully compelling, and has been queried by several researchers (Levitin & Zatorre, 2003; Vitouch, 2003).

Most of the available evidence for (or against) the early learning view is indirect, in that it relies mainly upon retrospective reports of the participants on the age at onset of music training. There is so far little systematic research investigating directly the time-course of AP development in childhood, and it is not yet clear how and when children acquire AP. This report is an attempt to investigate the learning process of AP by testing cross-sectionally children of ages 4 to 10 years in a music school for their pitch naming ability, thereby providing more direct empirical evidence for the possibility of learning AP by children. When the test was carried out, these children had been trained in piano playing at the music school since they entered the school at the age of 4. Consequently, the amount of the training they received varied depending on their ages at the time of testing.

Some caveats must be noted to this study. As this study was cross-sectional, not longitudinal, the factor of training, the primary interest of this study, could not be manipulated for the purpose of the experiment. Consequently, effects of training could not be directly evaluated. Furthermore, there might have been sampling biases among the different age groups due to dropouts. As well, older children may be more successful and more strongly motivated in the training. Nevertheless, with these limitations in mind, we propose that the results could be useful to draw a general picture of the learning process of AP.

The Training Program Children Received in the Music School

The children were enrolled in a private music school in Tokyo. This school is run by the largest music corporation in Japan and has a number of similar branch schools for children throughout Japan. Under its own music education system, music lessons are given to children for developing basic music skills for various musical activities. The main aim of the school is to encourage children in general to develop their capability to express themselves by music, not to train future professional musicians.

At the music school, children first enter the Primary Course, a 2-year program consisting of four semesters, with a 1-hour weekly lesson, in which the fundamental musical skills and ear training are emphasized through various music-related activities. In the first semester, children learn the notes C4, D4, E4, F4, G4, C3, and G3, through listening, singing, and playing piano. Of these notes, more emphasis is given to C4, D4, and E4, which are the beginning three notes of the C-major diatonic scale and are within the vocal range of the children. Instructors try to teach songs that consists of these three notes, and children learn the pitches and their pitch names through singing, memorizing, and playing the songs on the piano; for example, they (1) sing “Song of Bread,” the first song children learn, with lyrics, (2) sing the song in solmization (‘mi-re-do, mi-re-do, do-do-re-re-mi-re-do’) until they memorize it, (3) play the song on the piano, and (4) play the song on the piano while singing it in solmization. This song is repeatedly sung and played in lessons during the first 6 months.

In parallel with learning the songs, children learn each individual note. They first learn C (‘do’ in the fixed-do system) when playing the piano in the first stage. Instructors indicate that there are many ‘do’ keys on the piano keyboard and ask children where they are, thus helping children get an understanding of octave
equivalence. In learning C, children are encouraged to locate the ‘do’ key on the piano and to vocalize the same pitch as the produced sound when the key is pressed. In this process, they learn C4 as the pitch within the range they vocalize easily, C3 as lower one, C5 as higher one, and C6 as even higher one. D (re) and E (mi) are learned in the same manner. Then children learn other white-key notes, F (fa), G (sol), A (la), and B (si), principally in the same way, as new songs including more different pitches are introduced in the lessons. Therefore, C, D, and E, already learned, are more frequently repeated in the lessons. After all the white-key notes have appeared in the lessons, black-key notes are introduced one by one when pieces of different keys other than the C major come into the children’s repertoire. Specifically, children begin to learn F½ and B½ notes when the key of G major and F major are introduced. In the second year, the range of notes learnt increases from C3 to G5, and additional black-key notes, C♯, G♯, and D♯, are added. Thereby all 12 pitch classes are introduced.

Basic teaching techniques used for training in the primary course are imitative singing and immediate responding. Children are introduced to various types of singing activities including: (1) expressive songs, including well-known ones, sung with words expressively in a wide range of keys and musical styles; (2) drill melodies, which are composed with regard to rhythm, meter, keys, sequential/intervallic patterning, and children’s vocal ranges so that children can practice to sing the melodies in steady tempo and correct pitch. Children memorize about 20 melodies of 12 to 16 measures long (approximately 2/3 of them are in C major or A minor, and the others are in keys with one or two sharps or flats), and sing them repeatedly with solfège syllables (do, re, mi, etc.) in the fixed-do system, in which the C note is always named “do.” It is particularly emphasized that the children should produce the same pitches as those of piano tones played by instructors; (3) rhythmic songs—children sing these songs along with rhythmic motions; and (4) keyboard songs, songs children will later learn to play on the keyboard. In singing these songs using solfège syllables in the fixed-do system, children are prepared to play the songs on a fixed pitch level on the keyboard.

After the primary course, children are encouraged to take the Advanced Course (for the age of 6 to 10) to extend basic and applied music skills. In the classes of this course, children have the opportunity to play, compose, arrange, and improvise music. They learn pitch relations such as intervals and chords through playing and reading the materials for developing a sense of tonality and chord progressions.

Method

Participants. A hundred and four children were recruited from those who enrolled in piano classes in the music school for children in Tokyo. The parents signed an informed consent for their children to participate in the AP test. Children’s age ranged from 4 to 10 years, comprising 13 of 4 years, 18 of 5 years, 13 of 6 years, 14 of 7 years, 26 of 8 years, 14 of 9 years, and 6 of 10 years. All the participants had entered piano classes in the school at the age of 4. The participants of 4 and 5 years of age were in the Primary Course for younger children common to all children at the school; the participants aged 6 years and above belonged to the Advanced Course for selected children who had reached certain levels of musical achievements mainly in piano playing. All the children were tested about three months after the beginning of the school year; hence, for example, children of 4 years had received training of the school for three months.

Stimuli and apparatus. Two different timbres were used for test tones: tones produced by a Yamaha grand piano and string-like tones generated by a Yamaha electronic organ. The test tones consisted of 36 chromatic pitches over 3 octaves, fundamental frequencies of which ranged from 130.81 Hz (C3) to 987.77 Hz (B5) with a standard pitch of 440 Hz as A4. Test tones were presented in random order, with the restriction that successive tones were separated by more than 7 semitones (perfect fifth) and were not separated by octaves, in order to make it difficult to use relative pitch. The test was a modified-version of the AP test that reliably differentiated between adult genuine AP possessors and pseudo-AP possessors who relied on relative pitch (Miyazaki, 1990).

Procedure. The test sessions were conducted in a lesson room. There were two experimental sessions, the first for piano tones and the second for electronic-organ tones. The test session for the electronic-organ was not carried out for all children of 4 years, because they appeared to be unable to keep their attention across the two sessions. Furthermore, five children of 5 years, and one child of 9 years also did not proceed to the second session, because they appeared not to be willing to continue. Before the test session, there was an introductory session of an appropriate length in which the tester explained the instructions and gave several practice trials. Every care was taken, particularly in case of younger children, to make the children feel at ease in the test situation. In the test session, test tones were played by the tester who sat at the piano or the electric organ, facing the child on the other side. Children were tested
individually and were told to name the pitch class of the test tone out loud using their familiar solfège names (e.g., do, do-sharp, or re) in the fixed-do pitch naming system. Judgments of octave position were not requested. No feedback on correctness of responses was provided, but supportive words were always given to keep the participants’ motivation during the experimental sessions, even when they made an incorrect response. The whole experimental session was recorded by a video camera for later recording responses and measuring response times.

Results

Although piano and electronic-organ tones were used in the test, the presentation and analyses primarily focus on the results for the piano tones, because not all children were tested with the electronic-organ tones. Results for the electronic-organ tones are presented later only for examining effects of timbre on test performance.

As the accuracy measure of AP, the proportion of correct responses was calculated for each participant. Figure 1 shows the overall performance for the piano tones as a function of age. Open circles connected by a solid line show the average percentage of overall correct responses, and smaller dots superimposed represent the performance of the individual participants. This figure shows a general tendency for accuracy to increase with the participants’ age. The overall performance improves from near chance at the age of 4 to around 80% correct at the age of 7, but did not improve markedly thereafter. An analysis of variance (ANOVA) revealed a significant effect of Age Group, \( F(5, 98) = 79.06, p < .001 \). Tukey/Cramer multiple comparisons demonstrated that the age groups of 4 to 7 differed significantly each other (\( p < .05 \)), but there were no significant differences among the age groups 7, 8, and 9.
The data of the individual participants show a somewhat different picture. Although the general trend was a linear increase in accuracy of AP between the age 4 and 7, the accuracy of individual participants was widely distributed particularly at age 5 and 6. In these ages, children generally began to show an improvement in accuracy, but there were some whose scores remained near chance. Furthermore, variability in accuracy was also found in the children at age 7 and above. On the one hand, there were a substantial number of children who reached above 80% level; on the other hand, there were some who performed with only around 60% accuracy.

The test results for piano tones were further analyzed by calculating the proportion of correct responses separately for notes corresponding to the white keys and for notes corresponding to the black keys on the musical keyboard (Figure 2). Large open circles and closed circles connected by a thick line display the performance for the white-key notes and that for the black-key notes, respectively. Pairs of a smaller white and black circle connected by a thin line represent individual participants' performance for the white-key notes and for the black-key notes, respectively. As a whole, accuracy for the white-key notes developed consistently beginning from the age 4 and reaching a plateau at the age 7. Accuracy for the black-key notes, on the other hand, started to develop later in age; accuracy for the black-key notes showed no marked increase until the age 6, but a rapid increase between age 6 (16.4%) and 7 (57.1%) and a further slight increase at 8 (71.5%). Development of accuracy for the black-key notes seems to be about 2 years behind. The accuracy for the black-key notes does not catch up with that for the white-key notes even at the age of 8 and above when the performance as a whole reached a plateau.

![Figure 2](image-url)

**FIG. 2.** Percentage of correct responses of AP identification with piano tones by children of different ages. Scores for white-key pitches (open symbols) and black-key pitches (closed symbols) are shown separately. Larger dots connected by solid lines depict average scores and smaller dots depict scores of individual participants; a pair of smaller open and closed dots connected by a thin solid line represents each individual participant's score averaged for white-key pitches and black-key pitches, respectively. The thin dotted line represents overall scores of different age groups (the same as Figure 1).
The data were subjected to a mixed two-way ANOVA with the between-subject factor of Age and the within-subject factor of Note Category (white vs. black). There were significant main effects of Age, $F(5, 98) = 71.92, p < .001$, and Note Category, $F(1, 98) = 150.94, p < .001$. There was a significant interaction of Age by Note Category, $F(5, 98) = 4.22, p < .002$, and the simple main effect of Note Category was significant for all age groups, $p < .005$. Furthermore, Tukey’s multiple comparisons were conducted on the test data separately for the white-key notes and the black-key notes. For the white-key notes, the age groups from 4 to 7 differed significantly from each other, $p < .05$, but there were no significant differences among the age groups 7, 8, and 9. For the black-key notes, a significant difference was found only between the age groups of 6 and 7, $p < .05$.

For the results of the individual participants, variability in performance for the white-key notes was markedly large for the age groups of 5 and 6, but substantially decreased for the older age groups; apparently, most participants of age 7 and above developed nearly perfect accuracy for the white-key notes. On the other hand, variability in accuracy for the black-key notes was extremely large at age 7 and above; although most participants of these ages developed accurate naming of the black-key notes, there were a small number of participants in these age groups who failed to identify the black-key notes (scored 20% and below). It is particularly noticeable that these participants quite often had near perfect accuracy for the white-key notes.

Panels of Figure 3 show the response pattern in more detail. They display the response distributions for the piano notes as stimulus-response confusion matrices for different age groups. These matrices represent how often each pitch category was responded to a given stimulus tone (pitch class), and illustrate the developmental
process as the age increases. The performance of the children of 4 years of age was generally very inaccurate, except for C that was correctly identified 54% of the time. The high percentage correct identification of C should not be taken at face value, because the children of this age made C responses most frequently (33% of all responses) to almost all tones; as a result, they made a large number of errors taking the non-C notes as C. Generally, they selected as responses exclusively the notes without accidentals.

At the age of 5, the correct responses to the white-key notes began to increase, though the spread was still considerable. At the age of 6, responses for the white-key notes became fairly accurate, whereas responses to the black-key notes remained quite inaccurate; as a result, the difference in accuracy between the white- and black-key notes is the most pronounced at this age (as displayed also in Figure 2). This difference is apparently related to the response bias favoring the white-key notes. Of all the test tones, 80.8% were identified as white-key notes, whereas only 10.5% were as black-key notes (the residual 8.7% elicited no response). This bias toward the white-key notes is remarkable when compared with the ratio of 7 white-key categories vs. 5 black-key categories. With this response bias, the black-key notes were more often identified erroneously as the adjacent white-key notes than correctly identified; for example, C♯ was identified more often as C than as C♯, D#/E♭ more often as E than D#/E♭, and so on.

At the age of 7, correct responding to the white-key notes was largely established and showed no further increase after this age. On the other hand, naming the black-key notes markedly increased in accuracy at this age, but was still unstable and notes were sometimes confused with their neighboring white-key notes. The accuracy of the black-key notes further increased thereafter to over 70% correct reaching a plateau at the age of 8.
Figure 4 and 5 represent the performance for the electronic-organ tone as a function of age. Figure 4 shows that the general tendency of growth for the electronic-organ tone is similar to that observed for the piano tone, although the performance for the electronic-organ tone is somewhat lower than for the piano tone, particularly for children of 7 years and above. The lower performance for the electronic-organ tone is more clearly seen for black-key notes, as can be seen in Figure 5. A few cases suggest that the difference in performance between different instrumental timbres is related to the instrument children were most familiar with. For instance, three 5-year-old children who showed more accurate AP for the electronic-organ tone than for the piano tone had had experience in playing the electronic-organ prior to the piano.

A mixed 3-way analysis of variance with the between-subjects factor of Age Group and two within-subjects factors [Pitch Category (white vs. black) and Timbre] was performed on the percent correct data obtained from children who had taken both tests of the piano tone and the electronic-organ tone. Significant main effects were found for Age Group, $F(4, 80) = 34.08, p < .001$, for Pitch Category, $F(1, 80) = 209.37, p < .001$, and for Timbre, $F(1, 80) = 9.79, p < .005$. Significant interactions were found between Pitch Category and Timbre, $F(1, 80) = 5.82, p < .05$, and between Pitch Category and Age, $F(4, 80) = 3.84, p < .01$. For subsequent analyses on the interaction of Pitch Category by Timbre, planned comparisons showed that the average performance for the piano tone was significantly higher than for the electronic-organ tone only for the black-key notes, $F(1, 80) = 15.70, p < .001$, but not for the white-key notes.

Response times were measured only for responses to the piano tone from video recording as subsidiary data for the purpose of checking the possibility that the
children might use the relative-pitch strategy that could be expected to take a longer time. Although the children were not given any instructions emphasizing the need to respond quickly, they generally responded fairly quickly. The grand mean response time across all the children was 1.74 sec (SD = 0.58), with a range from 0.80 sec to 3.46 sec.

Discussion

The results reported here illustrate the process in which children improved accuracy in pitch naming as a function of years of systematic music training they received. In general, children's performance showed a significant increase in accuracy, beginning from the near chance level at the age of 4 and reaching a plateau at the age of 7. Particularly, it is noteworthy that almost all the children at the age of 7 and above achieved varying degrees of AP, ranging from an imprecise level (around 60% correct) to a level of perfect accuracy in identifying 12 pitch classes.

It is fair to notice the fact that the older children of ages 6 and above (the Advanced Course) had been selected according to the progress in their skills of piano playing, whereas the younger children of ages 4 and 5 (the Primary Course) were unselected. One might argue, then, that the difference in AP accuracy between the younger children and the older ones may be ascribed to the selection process. However, the increase in accuracy of AP is fairly gradual with no discernible discontinuity between the ages of 5 and 6. Moreover, the selection from the Primary Course to the Advanced Course in the school is rather liberal and is carried out with respect to the achievement in the general musical activities, not to AP ability at all. Therefore, we could safely interpret the growth function of AP accuracy as depicting the learning process of AP of the children who were and/or would be in classes of the Advanced Course.
Although almost all of the older children developed varying degrees of AP, it must be admitted that the high rate of improvements of pitch naming observed here cannot be generalized to the population of children in general because these results were obtained from biased samples. First of all, the children enrolled in the music school might have more interest and motivation in music, and their parents might be more music-education-minded. Furthermore, the children who participated in our study were not randomly sampled but were volunteers whose parents responded to solicitation with a high degree of interest in their children’s faculties. Therefore, our results do not indicate that every child in the music school is capable of developing AP, accurate or inaccurate. Probably, there might be many (unexamined) children who would fail to acquire AP among those attending the schools. Our results, therefore, do not provide any reliable information about the success rate of training AP. Nevertheless, considering that the music school has a large number of children in the branch schools throughout Japan and those schools are not intended for only a handful of musically talented children but are open to children in general, the high success rate observed here could still be considered to be a notable outcome.

One may raise the possibility that the accuracy observed in the present test might be overestimated for several reasons. First, the primary data on which our discussion is based were obtained from the AP test with piano tones. It is well known that piano tones are the easiest stimuli for AP identification, because they are most familiar to most musicians and have rich extraneous cues that possibly assist AP identification (see for example, Lockhead & Byrd, 1981; Miyazaki, 1989). Ward (1963) termed this phenomenon “absolute piano.” In the present experiment, an electronic-organ timbre was also used for comparison with the piano timbre. Indeed, the performance of the AP test with electronic-organ tones
was slightly but significantly lower than that of the AP test with piano tones but only for black-key notes. This difference in performance could be interpreted as reflecting the difference in children's familiarity with timbres. Notably, a few 5-year-old children who had received initial training in electronic-organ gave substantially higher performance in identifying electronic-organ tones than piano tones.

Second, it might be raised the possibility that children used a relative-pitch strategy in identifying AP, which could boost their performance even if they had not acquired AP. However, it seems unlikely that the children we observed actually took advantage of a relative-pitch strategy that is more demanding, because our AP test was constructed with great care to avoid a relative-pitch strategy. The response-time data indicating that the children responded relatively quickly also suggest that the children did not rely upon a relative-pitch strategy that takes longer time.

There are several previous studies that have attempted to demonstrate the learnability of AP by providing preschool children or adults with extensive training for acquiring AP (e.g., Brady, 1970; Cohen & Baird, 1990; Cuddy, 1968; Crozier, 1997; Russo et al., 2003). However, these attempts were only partially successful; the researchers studied but the beginning of the acquiring process of AP, which is far from the exquisite level of genuine AP. The present finding appears to stand in striking contrast to those previous studies. Most of the children we observed developed AP, though its accuracy ranged from imprecise to perfect. This difference in the outcomes of music training may be due to the difference in the purpose and the amount of the training given to the participants between our study and the previous attempts. In the previous studies, participants received solely the AP training that was designed for the purpose of investigating the development of AP and given over a limited
period of time. In contrast, the children of the present study received a broader spectrum of music training that eventually led to high performance on the AP test. It is perhaps the repetition of a limited number of notes associated with simple songs used in the lessons and the use of multiple methods (listening, singing, and piano playing) that facilitated to learn AP in the first stage of the lessons. Moreover, the children had probably much higher motivation; they themselves as well as their parents spent much more time and effort in the lessons according to the systematically designed training program over the course of several years. The children received lessons in keyboard playing at the school once per week and probably had everyday practice at home. The highly motivated learning and repeated exposure to the pitch-name relationship based on the fixed-do solfège in lessons of general musical activities are believed to be effective for acquiring AP. The question of why some children developed accurate AP while others did not may be accounted for, at least partially, by the possible variability in the amount of time and effort the children spent in the music lessons.

Other training methods designed more specifically for developing AP might be even more effective. For example, in the Eguchi-method for AP training (Eguchi & Eguchi, 2001), children at first learn to identify individual chords and then go on to differentiate component tones of the chords. Proponents of the method claim that the initial training of chord identification is most effective in acquiring AP because it enables children to focus on the tonal characteristics of individual chords as a whole without comparing pitch height of individual tones. In fact, the success rate is purported to reach more than 90% among children who were trained with their training program before the age of 6 (Eguchi & Eguchi, 2001; Sakakibara, 1999). However, it may be argued that training only AP is musically meaningless, even unfavorable to later music activities, as discussed later.
While children learned AP for each pitch class one by one according to the schedule of the school's system of music instruction as described above, it is noteworthy that there was a considerable time lag between the time they began to learn a particular note name associated with a specific pitch and the time they established the ability to identify individual musical pitches consistently. Thus, the 5-year-old children who had completed the 1-year lesson had been exposed to all white-key notes and some black-key notes by that time, but the results obtained here showed that they were not yet very accurate in naming those pitches; furthermore, the 6-year-old children who were supposed to know all the pitch-class names were indeed able to identify the white-key notes, but were very inaccurate in recognizing the black-key notes. It is as late as the age of 7 that most children were able to name all 12 pitch classes in the same manner as the adult AP listeners. This time lag indicates that it takes a considerable amount of time period for the AP ability to be stabilized. During this period, which is at least for 1 year, AP for particular notes may be established through repeated practices at school and at home including singing songs in the fixed-do solfège and playing the songs on the piano.

This relatively slow progress in establishing AP may be, partly, a consequence of the school's music instruction system that is not aimed at solely getting children to learn AP but places more emphasis on establishing general musical abilities including melody, harmony, and tonality. If children were given training focusing solely on acquiring AP, AP could have been more quickly established. Actually, some children who first learned AP with the fixed-do pitch naming system sometimes experienced confusion and often made errors in solfège singing later when they learned to play and sing songs in different keys other than the C major. This confusion suggests that AP conflicts with the tonality based on the sense of pitch relationships.
(relative pitch). Possibly, the introduction of different tonalities and relative pitch into the music lesson may cause confusions in absolute pitch naming, and consequently AP learning may suffer interference to some extent. Furthermore, we could speculate about the reverse possibility that AP, once established, may interfere with development of relative pitch. This should be more problematical to music. AP per se without considering musical context is irrelevant to music, and acquiring only AP would be even detrimental to musicians if they do not develop relative pitch to the full (see Miyazaki, 1993, 1995, and Miyazaki & Rakowski, 2002, for a discussion of a drawback of AP in music).

The present study also demonstrated a differential pattern of AP development for the white-key notes and the black-key notes, which could provide a plausible account for the difference in accuracy of AP between them and the existence of partial AP. Previous studies indicated that most AP listeners can identify the white-key notes more accurately and quickly than the black-key notes (Miyazaki, 1988, 1990; Takeuchi & Hulse, 1991). Inaccurate AP listeners tended to show this asymmetry more clearly. Hence, they could be classified as partial AP possessors (AP for only the white-key notes) (Miyazaki, 1990). The present results revealed that the development of AP for the black-key pitches started at the age around 6, about 2 years behind the development of AP for the white-key pitches. This time delay is supposed to be closely related to the practice of music training on piano, in which lessons generally begin with the easiest-to-play pieces in the C major mode that use only the white-key notes and then proceed to pieces in other keys with increasing accidentals that use more of the black-key notes. If AP can be most effectively learned during a limited period in early childhood (perhaps before the age 7), as early-learning theories claim (Sergeant & Roche, 1973; Takeuchi & Hulse, 1993; Ward, 1999), it is most likely that AP for the white-key pitches can be learnt, but AP for the black-key pitches may not develop in full. It is noteworthy that there were typical instances of partial AP in children of ages 7 and above who achieved the perfect level of performance for the white-key notes but fell to chance performance for the black-key notes.

The present study is concerned with the classic issue over the etiology of AP, that is, controversies between geneticists’ views that AP is an inborn ability that is inherited (Bachem, 1950; Baharloo, et al., 2000; Gregersen, Kowalsky, Kohn, & Marvin, 1999; Révézs, 1953), and early-learning views that AP is learned through extensive training or repeated exposures to musical stimuli during early childhood. These two classes of theories do not necessarily seem to be mutually exclusive, and it is inappropriate to apply a simplified form of the nature versus nurture controversy to the AP etiology. There may be a genetic basis for AP and indeed recent studies have provided some evidence consistent with it. However, geneticists’ studies revealing a high rate of familial aggregation of reported AP (Baharloo et. al., 2000; Gregersen et al., 1999) is inevitably contaminated by environmental or experiential factors (see, Levitin, 1999). More compelling evidence would be necessary to postulate a genetic basis of AP.

On the other hand, it is evident that learning is a necessary condition of musicians’ AP, and there is a rich body of literature suggesting that experience, particularly in early childhood, is critical to acquisition of AP (Miyazaki, 1988; Sergeant, 1969; Takeuchi & Hulse, 1993; for an overview see Vitouch, 2003). A strong form of the early-learning theory of AP makes the two related claims that AP develops through music training within a critical period in early childhood and that training after the critical period does not produce AP. However, these claims have been often postulated merely on the basis of several lines of indirect evidence that many AP possessors report retrospectively that they began music training at an early age and that adults are incapable of acquiring AP even after extensive training. The present study offers more direct evidence for the former claim of the early-learning theory of AP; the children in age from 4 to 7 achieved a substantial increase in overall accuracy of AP. However, the present study is not directly concerned with the latter claim of the theory, that is, the ineffectiveness of the training at later ages in developing AP, because we did not test children who had begun their training at later ages. Nonetheless, our results provide evidence consistent with the latter claim. There were some children with inaccurate AP at the age of 7 and above; particularly, AP for the black-key notes did not show a marked improvement after the age of 7. This suggests, though not so compellingly, that the critical period for the development of AP expires at about 7 years of age. More convincing evidence that would be obtained from the study including children commencing music training at later ages will be needed to determine this hypothesis. In any rate, early learning is undoubtedly a necessary condition for AP acquisition, but not a sufficient one. Our study does not settle the issue of etiology of AP, but it could be argued that our data provide
direct evidence for the learning process of AP during music training in childhood, that is consistent with the early-learning view of AP.

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