Psychology of Music
http://pom.sagepub.com/

A longitudinal study of the process of acquiring absolute pitch: A practical report of training with the 'chord identification method'

Ayako Sakakibara

Psychology of Music 2014 42: 86 originally published online 29 October 2012
DOI: 10.1177/0305735612463948

sempre:
Society for Education, Music and Psychology Research

Article

Psychology of Music
2014, Vol 42(1) 86–111

DOI: 10.1177/0305735612463948
pom.sagepub.com
SAGE

A longitudinal study of the process of acquiring absolute pitch: A practical report of training with the 'chord identification method'

Ayako Sakakibara
Ichionkai Music School, Tokyo, Japan

Abstract

The purpose of this study was to investigate longitudinally the process of acquiring absolute pitch (AP). Twenty-four young children (aged 2 to 6 years) without AP were trained to acquire AP using Eguchi's (1991) Chord Identification Method (CIM). All children were able to acquire AP (except two who ceased training). Results suggest that, at a minimum, children younger than 6 years old are capable of acquiring AP through intentional training. Furthermore, children's errors observed during training suggested the transition of different strategies relying respectively on tone height and tone chroma. Initially, children identified chords using a strategy depending primarily on tone height, then gradually they began to attend to tone chroma to identify chords and this process ultimately led to acquisition of AP.

Keywords

absolute pitch, chord identification, training to acquire absolute pitch

Absolute pitch (AP) is the ability to identify pitch by its tone name in the absence of a reference tone. The proportion of people who possess AP is estimated to be less than 0.1% of the general population (Bachem, 1955; Profita & Bidder, 1988) and about 15% among musicians (Baharloo, Johnston, Service, Gitschier, & Freimer, 1998). The topic of AP acquisition is an issue of long-standing controversy that has been addressed by various theories. Different theoretical approaches range from the nature theory, which claims that AP reflects an inherent ability, with only a few people exhibiting this trait, to an extreme nurture theory, which holds that anyone can acquire AP, regardless of age. In recent years, an early-learning theory has gained traction (for detailed reviews see Chin, 2003; Levitin & Rogers, 2005; Rakowski & Miyazaki, 2007; Takeuchi & Hulse, 1993; Vitouch, 2003; Ward, 1999). Early-learning theories posit that music training in early childhood is especially effective in the development of AP.

Corresponding author:
Ayako Sakakibara, Ichionkai Music School, Tokyo – Psychology, 3-19-2 Nagasaki Toshima-ku, Tokyo 1710051, Japan.
Email: sakakiba@kg8.so-net.ne.jp

This article outlines four sources of evidence consistent with an early-learning approach to AP. The first approach reflects the oldest line of AP investigation: it examines the proportion of AP possessors with regards to the function of onset age of musical training (Baharloo et al., 1998; Deutsch, Henthorn, Marvin, & Xu, 2006; Gregersen, Kowalsky, Kohn, & Marvin, 1999; Profita & Bidder, 1988). For instance, Baharloo et al. investigated the age at which musical training began in 612 musicians and found that those who started training earlier had a greater likelihood of exhibiting AP. They identified five age categories with respect to the onset age of music lessons (4, 4–6, 6–9, 9–12, and over 12 years of age) and found that the proportion of AP possessors was inversely related to onset age of training for these age groups. The AP percentages, respectively, were: 40, 27, 8, 4, and 2.7%. Miyazaki and Ogawa (2006) also noticed the existence of partial AP possessors, namely individuals who could identify pitches for only white-key notes of a piano keyboard. This finding is also consistent with early-learning theory because music training on piano generally begins with simple pieces in the C major mode that use only white-key notes. Moreover, the age at which people usually learn pieces that include black-key notes is considered to be too late to acquire AP.

The second source of evidence for early AP learning comes from reports that younger children exhibit a relatively strong tendency to rely upon absolute values of stimuli. Young children appear to use the absolute height of pitches for remembering or identifying pitches. In the first published report on this topic, Sergeant and Roche (1973) asked 3- to 6-year-old children to reproduce melodies three weeks after they learned them. They found that younger children reproduced the absolute pitches of these melodies more accurately than did the older children, whereas the older children reproduced the relative features of melodies more accurately than younger children. More recently, Saffran and colleagues (Saffran, 2003; Saffran & Griepentrog, 2001) reported that 8-month-old infants used absolute pitch cues in a tone-sequence statistical learning task, whereas adults tended to rely on relative pitch cues. Stalinski and Schellenberg (2010) asked adults and children 5–12 years of age to rate how different two melodies sounded. They found that younger subjects perceived two melodies that were pitch transposed – hence with identical pitch contours – as different, thus suggesting that these children based their judgments on absolute rather than relative pitch. Together such findings suggest the presence of an absolute-to-relative developmental shift in the perception of pitch. Such a shift is consistent with early-learning theory.

The third source of relevant evidence for early AP learning involves data showing that the proportion of AP possessors differs as a function of ethnic background. Gregersen et al. (1999) conducted a large-scale survey in which 2,707 people reported the age at which they began music training and whether or not they possessed AP. Results indicated that the proportion of AP possessors in Asian students was 32.1%, whereas for non-Asian students this percentage was much lower at 7%.

Two separate research hypotheses have been advanced to explain these differences. The first maintains that an important determinant in the development of AP is whether or not a person is a native, or fluent, speaker of a tone language—for example, Mandarin Chinese, Thai, or Vietnamese. In tone languages pitch can convey word meaning. Thus this hypothesis holds that this type of tonal linguistic system facilitates a sensitivity to pitch. Supporting evidence comes from Deutsch et al. (2006), who found that, even accounting for the onset age of musical training, the prevalence of AP was greater among Chinese students who spoke a tone language (Mandarin) than among American students. In addition, Deutsch, Dooley, Henthorn, and Head (2009) reported that the prevalence of AP was significantly higher among Asian students who were highly fluent in a tone language compared with Asian students who were not. The performance level of Asian students who were not fluent in a tone language did not differ significantly from that of non-Asian students who spoke only non-tone languages. These researchers concluded that the kind of language experienced early in childhood influenced the prevalence of AP.

An alternative hypothesis concerned differences due to ethnic background. This hypothesis maintains that exposure to 'fixed do' musical training in early childhood facilitates children's development of AP. In fixed do training, a pitch always has a single name, whereas in 'movable do' training, a pitch can have various names depending upon different musical scales. It is supposed that fixed do training reinforces an association between a tone's pitch and its name, thus providing an advantage in the acquisition of AP. Some researchers have observed that Asian children are more likely to receive fixed do training in their early childhood than are Caucasian children (Gregersen, Kowalsky, Kohn, and Marvin, 2000; Levitin & Rogers, 2005). Additionally, the type of training in childhood tends to influence the strategy used to identify pitch. For example, Hsieh and Saberi (2008, 2010) reported that AP possessors who received fixed do training were influenced by the solfège syllable in a task where they had to identify pitches with a correct or incorrect solfège syllable; by contrast, in the same task those AP possessors who received movable do training were able to ignore the syllable. Both of these interpretations consider the role of ethnic differences and both imply that the nature of cultural experience gained in early childhood, whether from language or music, has a special impact on the acquisition of AP. This implication supports early-learning theory.

Finally, the fourth area of evidence for early AP learning arises from attempts to induce AP through training. Results of AP training with adults have not produced sufficiently strong outcomes to establish that training has a significant effect. Although some adults showed significant improvements in pitch naming, they did not reach a level of performance that justified an inference of AP acquisition (e.g., Brady, 1970; Cuddy, 1968, 1970; Meyer, 1899; Mull, 1925; Wedell, 1934). However, Crozier (1997) found a training effect with children: pre-school children (4–5 years) who received prior training showed significantly greater improvement in identifying a certain tone (A4) than did adolescents (13–15 years). However, these findings also indicated that adolescents performed consistently higher than pre-school children on tests before and after training. Thus this study failed to establish that pre-school children were superior to adolescents in tone identification. Russo, Windell, and Cuddy (2003) conducted three weeks of training with children (3–6 years) and adults, who subsequently identified a single tone, C5. Identification accuracy of children aged 5–6 years was superior to that of younger children aged 3–4 years, and to that of adults. These researchers concluded that the age range of 5 to 6 years was most appropriate for effective AP training and acquisition. Miyazaki and Ogawa (2006) investigated skill levels of 104 children (4–10 years) in a pitch identification task following fixed do training. The results showed a systematic growth in the average percentage of correct responses that increased with both age and the length of training periods. This suggested that appropriate education prompted the development of AP. The fact that the training for young children produced significant results, whereas that for adults did not, supports early-learning theory.

These four sources of evidence for early AP learning provide a diverse body of work suggesting that early training in music is a necessary but not sufficient condition for development of AP. The reason that the type of AP training has not yet been clearly established as a sufficient condition for AP acquisition is that the evidence favoring early learning is largely indirect: it is based primarily on correlational data. Stronger evidence will depend upon investigations designed to determine what methods of training ensure AP. A few studies have attempted to examine the effect of AP training methods with children; however, these have produced inconclusive results. For example, Crozier (1997) and Russo et al. (2003) attempted to train young children, yet their subjects did not exhibit AP ability. To date, a study by Miyazaki and Ogawa (2006) reflects the only attempt to focus upon the role of the training process itself in the development of AP. However, this attempt failed to investigate the learning process as a whole, nor did it examine the nature of individual changes over the course of training. In other words, it was a cross-sectional, not longitudinal, design. Furthermore, it is important to train young children using a method that has a clear potential for ensuring acquisition of AP in order to investigate critical aspects of the process involved in acquiring this skill.

In the present study, young children who did not initially possess AP participated in training until they reached a level of skill that reflected successful acquisition of AP. In addition, each individual's evolution in the longitudinal paradigm was examined throughout the process of AP acquisition. This research reports the details of this process.

First, the rationale and method used in the study are briefly outlined. The training method adopted was the Chord Identification Method (CIM) for AP acquisition proposed by Eguchi (1991). This method was chosen because of its high success rate and because details of the training procedure have been extensively outlined. More than one method should be used to examine the general process of acquiring AP; however, at present there is no method more detailed than the CIM.

Eguchi claimed that over 90% of the children she trained acquired AP through this method. The criterion used to indicate AP ability in her work held that a subject must be able to identify tone names with 100% accuracy in a criterion test involving 30 trials, each involving the presentation of a single piano tone without feedback. Figure 1 is an example of the criterion test. Previously, Cohen and Baird (1990) tried unsuccessfully to train young children using the CIM. They trained eight children (2–4 years) three times a week for approximately 5–10 minutes per session, asking subjects to identify three kinds of chords in a total of four or five sessions. It is likely that they failed to reach the AP criterion because both the frequency and length of training periods fell short of what is sufficient to establish AP. That is, the CIM requires daily practice. According to Eguchi's instructions, training must comprise four to five daily sessions of 2–5 minutes each, in which each session consists of 20–25 chord identification trials. Moreover, training should continue for a duration of at least two years. In light of this, the total of four or five sessions used by Cohen and Baird equals only one day of the CIM training. Additionally, the use of only three kinds of chords also deviates from the recommended number of chords for this method. In sum, the amount and method of training used by Cohen and Baird appears to be inadequate to ensure acquisition of AP. Sakakibara (1999) reported some cases in which subjects acquired AP through the CIM; however, the details of this study have not been published in English. Moreover, the sample size (four children) was very small in this investigation. In order to comprehensively examine the effect of the CIM a larger sample size is necessary.

In the present study, 24 young children (aged 2 to 6 years) were trained using the CIM. The procedure was structured to accommodate the frequency and length of training described by Eguchi for an assessment of whether or not the children could acquire AP. Eguchi claimed that over 1,000 children acquired AP through this method; however, confirmation of this claim is not possible as the data are unavailable. To assess the effectiveness of the CIM it is necessary to use methods that examine data from practice sessions, and additionally to investigate the

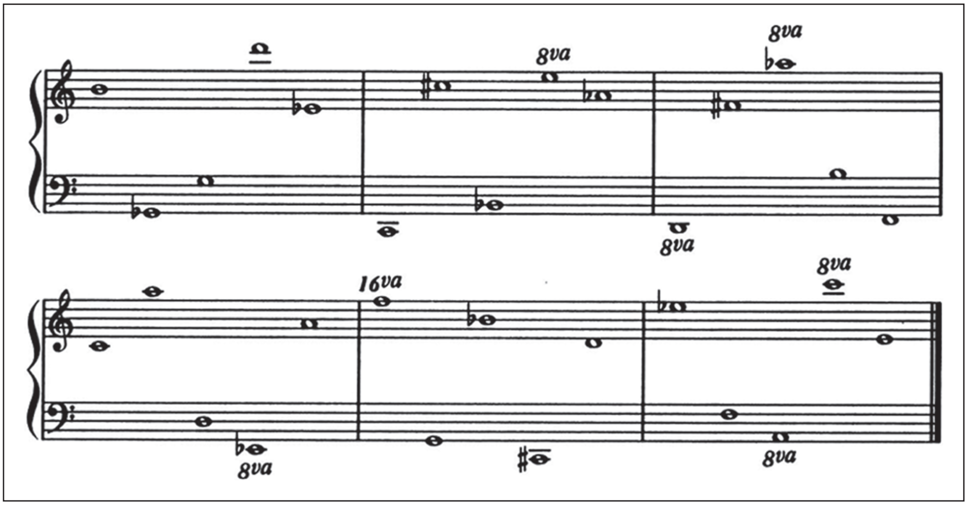


Figure 1. Example of criterion test for AP.

processes involved in the longitudinal acquisition of AP. However, because the processes observed in this study were based on the CIM, we must be cautious in generalizing the results of this study to the overall process of AP acquisition. Nevertheless, no previous study has examined the processes of acquiring AP longitudinally. Accordingly, the present research was designed to illuminate pertinent aspects of this learning process.

The Chord Identification Method

Procedures used in this research follow those outlined by Eguchi in her directions covering the CIM (1991) and are described in the following paragraphs (procedures of the CIM have been described in five books published in Japan since 1991).

This training consists of daily chord identification tasks. Every day, four to five training sessions are carried out, each comprising 20–25 identification trials. This amounts to a total of about 100 trials a day. Each session lasts between 2 and 5 minutes, and the set of sessions can be distributed across different times during a day. Sessions are short due to the concentration limitations of young children. In a session, a child begins by repeatedly listening to one chord represented by a small colored flag. Next, a trainer adds another chord, denoted by a second flag, and asks the child to identify each of the two chords by selecting their representative flags. This continues until the child can identify the presented chords with 100% accuracy. The trainer then presents the child with new chords one at a time. The timing of each additional chord is constrained to two or more weeks after the addition of the prior chord. (The aim is to prevent making the task too complex for the children). If a child does not identify the chords accurately two weeks after the last addition, the trainer then cannot add another chord and must continue with the same number of chords as in the previous session. In cases in which children make many mistakes and these errors appear to cause problems for the children, trainers must sometimes reduce the number of chords. However, reductions are a last resort because they tend to lessen the children's motivation. When the mistakes do not cause distress, trainers are advised not to reduce the number of chords.

The training process is divided into three successive periods: the period for white-key notes and memorization of nine kinds of chords; the period for black-key notes and memorization of 5–15 kinds of chords; and a practice period aimed at maintaining memorized chords. Although individual differences are great, in general it takes around one year of training with white-key notes and about six additional months of training with black-key notes. Finally, a child has to continue this practice until he/she reaches the age of 9 in order to maintain these skills.

Period for white-key notes

Figure 2 shows nine kinds of chords for white-key notes required for training to ensure AP acquisition. This set is referred to as 'nine white chords.' The order in which chords are added follows that shown in Figure 2, along with numerical labels (1–9). Trainers did not instruct children as to what tones or how many tones comprise a chord during the period of training for white-key notes. To this end, each chord corresponds to a color and children had to learn to answer with a correlated color name. Table 1 shows the correspondence between the nine white chords and their colors. The correspondence between the chords and their colors, while arbitrary, is nonetheless identical for all participants with this method.

Eguchi stated that, with no exceptions, all children who identified the nine white chords with 100% accuracy could acquire AP for white-key notes. Furthermore, she reported that even young children who met this identification criterion for nine white chords had no difficulty in achieving perfect identification of chords for black-key notes. Therefore identification of the nine white chords with 100% accuracy was a key to determining whether or not a child could acquire AP.

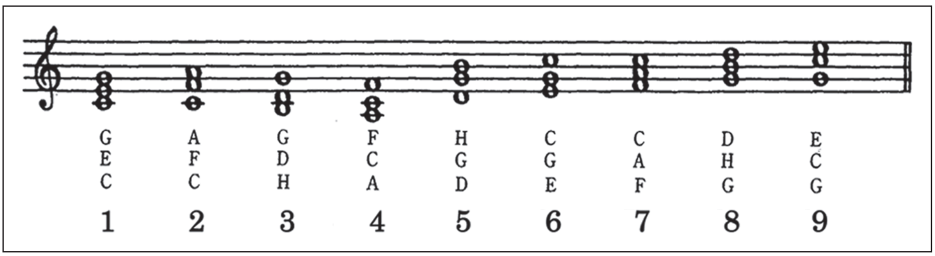


Figure 2. Nine white chords, ensuring AP for white-key notes.

Table 1. Correspondence between chords and colors in 'nine white chords'.

Chord	Color
CEG	Red
CFA	Yellow
HDG	Blue
ACF	Black
DGH	Green
EGC	Orange
FAC	Purple
GHD	Pink
GCE	Brown

Period for black-key notes

Training should begin with chords for black-key notes only after a child identifies the nine white chords with 100% accuracy. Chords for black-key notes comprise, at a minimum, five kinds of chords. Occasionally the first and second inversions of these chords are added, thus the period can involve up to 15 kinds of chords. Figures 3 and 4 show the minimum (five) and the maximum (15) chords, respectively. These sets are referred to as 'five black chords' and '15 black chords.' The naming system for these chords changes from color names to tone names when a child can identify the nine white chords correctly. During the period for black-key notes, children have to call all chords, including both black and nine white chords, by tone names, in response to trainers' instructions regarding names of tones that comprise the chords. Trainers should add black-key chords to the previously learned nine white chords one at a time, with the method being identical to that employed during the period in which the nine white chords are learned. Therefore, first, trainers add five black chords in without any inversions. When the children can identify 14 chords (i.e., nine white chords plus five black chords) accurately, trainers do not need to add additional chords. Only when a child cannot achieve identification of these 14 chords does a trainer need to add inversions of a chord that a child has trouble identifying. The 15 black chords are the sum of the five black chords and their inversions. For example, if a child cannot identify 'AC#E,' the trainer would add 'C#EA' and 'EAC#.' In this way, the number of chords, or the order of presentation of these 15 black chords, varies with each individual, and trainers must present all the chords appropriate to the needs of a particular child. Perfect identification in the period for black-key notes, defined by 100% accuracy across all essential chords, ensures acquisition of AP for black-key notes.

Practice period for maintaining ability

Trainers do not need to continue active practice with a child if he/she can perfectly identify all chords after the learning period for black-key notes. But Eguchi cautioned that children younger than age 9 are at risk of losing AP ability, thus practice should continue to preserve this ability even after the period for black-key notes has been completed. The aim of practice during this period is maintenance rather than training; the frequency of practice can be reduced as long as the child maintains performance. This practice, which occurs as frequently as four or five

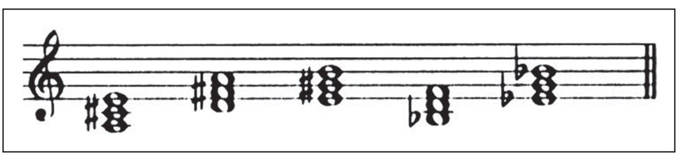


Figure 3. Minimum five chords ensuring AP for black-key notes ('five black chords').

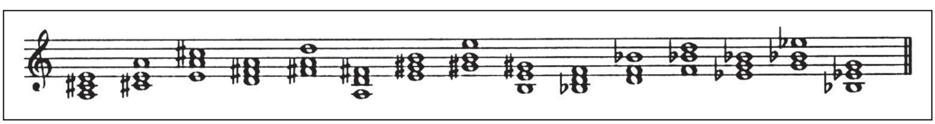


Figure 4. Maximum 15 chords ensuring AP for black-key notes ('15 black chords').

sessions per day during a training period for chord learning, can be reduced to as little as a single session a week. Trainers need to ensure that children maintain their ability to identify the chords through the practice period and sustaining this ability must continue until the child reaches the age of 9.

Because the naming system changes from color to tone at the onset of the learning period for black-key notes, the purpose of training also changes from whole chord memorization to a procedure designed to prompt children to selectively attend to a single tone within a chord. According to Eguchi, some children developed the ability to identify a single tone, in part by learning only 14 chords (nine white chords and five black chords). However, their pitch identification was insufficient at this point in the overall training program. That is, they were only able to identify some single tones within a limited middle register. Thus additional practice was required before such children could decompose a whole chord to identify the individual component tones. Accuracies of identifying single tones gradually improved during the maintenance practice period.

Method

Participants

Twenty-four children (aged 2 to 6 years) without AP engaged in training for this study. Table 2 shows gender, age at initiation of training, as well as prior musical training of participants. Eguchi said that children who began training at 8 years of age or older could not acquire AP, therefore the CIM is not considered to be effective for children older than 7. For this reason, children younger than 6 years of age were used as participants. The average age of the children starting the training was 4 years, 2 months.

Participants were children who attended a music school in Tokyo. The training procedure was explained to their parents in advance; all parents expressed a desire for their children to receive this type of musical instruction. Parents were informed that participants could stop the training at any time if they wished. Seven participants out of 24 had previous experience of musical training, consisting of various types of music lessons. The absence of AP was confirmed for all participants in a pitch identification test conducted prior to training.

Procedure

Participants were trained using the CIM on a daily basis at their homes. The pianos at participants' houses were tuned before starting this study, and a member of each participant's family was enlisted to act as a trainer. These trainers played stipulated chords on the home pianos and recorded the children's responses during training. The training had to be identical each time it was conducted. The small flags with colors corresponding to the chords (see Table 1) were set in front of participants. All flags with colors (chords for black-key notes were white flags with printed tone names) used for a session were simultaneously present. Participants answered during the chord identification tasks by holding a flag corresponding to the chord and saying its color or tone name. When a participant made a mistake, the trainer told him/her the correct answer and played the chord again. Participants had to hold the correct flag while reporting its color or tone name of the chord. Daily training consisted of 4–5 sessions; each session had 20–25 trials (it took 2–5 minutes). The time of day at which training took place was not fixed.

Table 2. Profiles and results of 22 participants*.

Case number	Name	Gender	Age of initiation of training	Prior musical training	Length of period for identification of 'nine white chords' (weeks)	Length of period for identification of 'five black chords' (weeks)	Age of perfect identification in criterion test	Week of first appearance of error depending on 'chroma'	Number of chords at first appearance of error depending on 'chroma'	Average of error depending on 'height' (%)	Average of error depending on 'chroma' (%)	Average of error of no answer (%)
1	HG	M	2 y 4 mo	No	50	68	5 y 5 mo	14	5	10.64	2.13	1.77
2	YK	M	2 y 9 mo	No	32	50	6 y 2 mo	14	6	0.94	0.26	2.55
3	SA	F	2 y 10 mo	No	62	70	10 y 2 mo	18	4	14.81	4.51	7.78
4	TN	F	2 y 11 mo	Pf. (3 mo)	26	46	6 y 0 mo	16	5	1.04	1.45	0.17
5	TO	M	3 y 4 mo	No	60	94	6 y 5 mo	24	5	5.44	1.44	0.26
6	IS	F	3 y 6 mo	No	64	78	6 y 4 mo	14	6	7.44	1.73	5.46
7	KM	F	3 y 7 mo	Pf. (2 mo)	30	54	6 y 6 mo	14	7	1.83	3.17	0.17
8	MR	F	3 y 8 mo	No	36	62	8 y 2 mo	26	8	4.52	0.52	0.49
9	AM	F	3 y 11 mo	No	46	52	8 y 6 mo	18	6	10.01	1.09	3.40
10	TM	F	3 y 11 mo	No	52	62	10 y 5 mo	22	6	9.65	0.69	1.50
11	SW	F	4 y 1 mo	Pf. (6 mo)	44	74	7 y 9 mo	14	5	5.74	1.72	0.92
12	YA	M	4 y 2 mo	No	38	50	6 y 11 mo	18	6	3.45	0.99	0.58
13	ST	M	4 y 2 mo	Pf. (6 mo)	30	46	9 y 0 mo	12	5	1.70	0.44	4.30
14	MW	F	4 y 3 mo	No	76	88	10 y 10 mo	22	6	13.11	1.60	2.11
15	IA	F	4 y 6 mo	No	44	58	7 y 7 mo	14	6	5.81	1.06	0.81
16	SY	M	4 y 7 mo	Vln. (2 mo)	48	72	8 y 0 mo	14	6	4.20	0.73	0.17
17	SH	F	4 y 7 mo	No	28	38	9 y 4 mo	20	8	9.13	0.63	1.19
18	KY	F	4 y 9 mo	Pf. (9 mo)	34	60	10 y 7 mo	12	6	2.92	3.40	1.57
19	NK	F	4 y 9 mo	No	38	44	12 y 9 mo	26	8	5.34	1.21	3.23
20	MS	F	5 y 4 mo	Pf. (4 mo)	24	36	7 y 6 mo	16	6	1.30	0.28	0.00
21	IK	M	6 y 1 mo	No	30	40	9 y 7 mo	22	7	6.89	0.67	0.22
22	TI	F	6 y 7 mo	No	22	34	14 y 8 mo	14	7	2.65	1.52	0.20
Average					42.21	58.00		17.45	6.09	5.84	1.42	1.77

*Pf refers to piano and Vln refers to violin.

Trainers were required to submit records (to the author) of daily practice and reports of participants' progress once every two weeks. This material was analyzed to ascertain the manner in which the practice period should progress. This mainly consisted of instructing trainers whether or not a new chord was to be added. In detail, when a participant was confirmed as having correctly identified all preceding chords, the trainer was told to add a new chord. Conversely, when a participant could not identify all chords perfectly, the trainer was told not to increase the number of chords. When the trainer reported that a participant was concerned about mistakes in chord identification, then occasionally a trainer would be urged to exclude chords responsible for these mistakes. These instructions were given to the trainers on a biweekly schedule.

Results

Twenty-two participants out of 24 were able to conduct the amount of daily practice needed for the chord identification method, 4–5 sessions a day, almost every day throughout the period of the training. Two participants stopped the training for personal reasons unrelated to the current project. The remaining 22 participants who continued the training were able to acquire AP.

Table 2 shows the profiles of the 22 participants and results of the training. From left, the columns of Table 2 show name, gender, age at initiation of training, and their prior musical training, as well as the length of the period (weeks) from the onset of training to demonstration of perfect identification of the nine white chords, the period up to the perfect identification of the five black chords, and the age when participants passed the criterion test for AP.

All 22 participants identified the five black chords perfectly and finished the training without adding the inversions of these chords. Eguchi stated that it was not necessary to add the extra chords when children could identify the five black chords. Therefore the most substantial period of training extended from onset of training to perfect identification of the five black chords. The average length of the period up to identification of the nine white chords was 42.2 weeks (about 10 months and two weeks), and the average length up to identification of the five chords was 58.0 weeks (about 14 months and two weeks). A great difference was observed in the length of the training among participants. The shortest training period for the nine white chords was 22 weeks (case 22) with the longest amounting to 76 weeks (case 14). The shortest period up to identification of the five black chords was 34 weeks (case 2) and the longest was 94 weeks (case 5).

The length of the training did not differ as a function of musical training prior to the present study; the difference between participants with and without prior training was $t(20) = -1.822$, ns, for the nine white chords and $t(20) = -0.488$, ns, for the period up to the five black chords. Additionally, the correlation between the length of the training and age of onset was not statistically significant: for the period for the nine white chords, $r = -.412$, ns; for the period up to the five black chords, $r = -.491$, ns.

The age when the participants passed the criterion test in Table 2 indicates the age at which they could perfectly identify all pitches in the criteria listed in Figure 1. Pitches in the test were presented as piano tones without feedback. Participants responded by saying the tone name. Assessment of each participant's ability to identify single tones occurred once every six months in order to monitor their development during the period of maintenance practice. The age at which they first achieved perfect identification of single pitches was recorded.

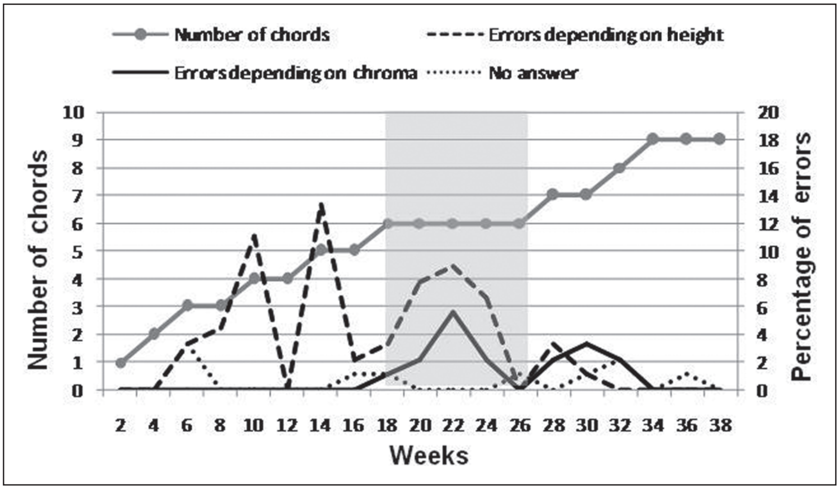


Figure 5. Changes of number of chords and percentage of three types of errors in case 12.

In this study, the analysis focuses on the periods that reflect the children's training in identifying the nine white chords because Eguchi specifically noted that a child's ability to achieve perfect identification of the nine white chords determined whether or not this child had acquired AP.

Number of acquired chords

As an index of the process of AP acquisition, the number of chords that participants identified in the daily training was assessed. Whether another chord should be added or not depended on the participants' performance at that point. The number of acquired chords was appropriate as an index of participants' abilities to identify these chords.

Results are illustrated using a single typical case, shown in Figure 5 (case 12; the other 21 cases – i.e., excluding case 12 – appear in Appendix 1). This figure shows the number of acquired chords as a function of weeks in training (in 2-week units) on the horizontal axis (it also contains other data discussed later). The number of acquired chords for this one participant is given on the leftmost vertical axis and the change in the number of chords over weeks is plotted by a gray line. This participant started training at the age of 4 years, 2 months (the average beginning age for participants).

Figure 5 illustrates a commonly observed, stepwise function over weeks. Notice that an initial rise in chord acquisition occurs from the first week which flattens out around week 18; at this point, a plateau sets in during which this participant is able to correctly identify only six chords for the next eight weeks. However, at the end of the 28th week, another chord is added and at this point the number of chords begins to rise again until it finally asymptotes at week 38. The plateau in this function was characteristic in that it was a common feature observed in performance of most participants. This period is referred to as the doldrums; it is specified in Figure 5 by gray shading. The doldrums were the periods during which the number of chords temporarily ceased to increase.

Appendix 1 shows the changes of the number of acquired chords for each of the other 21 cases (participants) except for case 12 (Figure 5). The number of chords increased over time in almost all cases because, as previously indicated, reducing the chords might lower participant motivation. However, in some cases, the participants had difficulties in identifying chords; in these cases, the number of chords used was briefly decreased. The length of the time up to the perfect identification of nine white chords varied from 22 weeks to 76 weeks: the length of the longest case was three times longer than that of the shortest case.

Despite great individual differences in the length of the doldrums, in all cases two features appeared to be common to progress regarding changes in chord numbers. The first feature involves the rate of learning new chords: this was not constant throughout training for all participants. Overall, the acquisition of new chords exhibited a stepwise function over time. That is, over time the number of chords generally increased relatively rapidly initially, then leveled out for a period of time; during this plateau the same number of chords was maintained, after which the participants' rate of learning increased again as they began once more to slowly learn new chords.

The second feature is that this plateau began with five (to seven) chords. The plateau (the doldrums) appeared in other cases (see Appendix 1). In fact, some kind of plateau was found in all cases. However, in some cases it was difficult to partition out the exact times of doldrums. For instance, the doldrums in case 1 appeared when this participant acquired about seven chords (i.e., at presentation of chord 7 in Figure 2), but the plateau was not distinct because the overall rate of increase for these chords was very gradual. Similarly, determinants of the doldrums in cases 8, 10, 18, and 21 were not clear because in these cases the number of chords changed during the plateau. However, the doldrums usually began after about five (to seven) chords had been presented. That is, around presentations of chords 5–7 the where a plateau begins this plateau indicates that the addition of new chords was slowed.

Only two cases (cases 4 and 17) were exceptional. The plateau between chords 5–7 did not appear. In both cases the plateau began with the presentation of the third chord in the ordered series. We found a small plateau at the beginning of training in other cases, too (cases 1, 2, 5, 8, 14, and 21). The plateaus for cases 4 and 17 were also considered to be relatively brief and occurred early in training. The reason for the absence of doldrums at the usual time during training (i.e., after five to seven chords) is not clear. A common feature in both cases was that the length of the period up to the identification of nine white chords was shorter (around 26–28 weeks) than in the other cases (average length of 42.2 weeks). This suggests the possibility that the absence of doldrums that begin with chords 5–7 depends on early acquisition of the full identification of the chords. However, this remains only a hypothesis.

The other 20 cases shared a common feature: all exhibited a certain doldrums plateau and the number of chords learned at the onset of the doldrums was between five and seven. Consequently, we can conclude that doldrums, which begin after about five or seven chords, are a common characteristic present in all cases except two.

Abstraction of the types of errors.

Participants sometimes made errors in daily chord identification training. Several methods were tried to in order to reduce the rate of these errors. Although error rates were not high, they nonetheless hold implications for understanding the processes participants used to identify chords. As an additional index of the process involved in AP acquisition, errors reflecting chord identification strategies were assessed.

The analysis of errors was based on records of a participant's practice over a period of two days. These records contained about 200 trials and the days to be analyzed were set at one week after instructions whether a new chord was added or not. Analysis of practice immediately after adding a new chord was not appropriate for the investigation of a change in the overall process because many errors temporarily related to the new chord were observed. Therefore the training record beginning one week after addition of a new chord was examined in order to construct an abstraction of a stable listening strategy. Families received appropriate instructions once every two weeks; thus the records on which the analysis is based represent the midpoint between these instructions.

Errors are classified according to two established pitch dimensions: tone height and tone chroma, as suggested by Revesz (1913) and Bachem (1937). Height is a sensation of natural pitch corresponding to linear frequency changes (e.g., from low to high), whereas chroma refers to an octave circularity inherent in named musical pitch classes within each octave. The former has continuous value and the latter categorical value. Thus training errors can then be classified into the following three types of errors.

Errors depending on height. Errors associated with pitch height were caused by confusions among chords of similar heights. The chords used in training were ranked according to height (from lowest to highest) as: ACF, BDG, CEG, CFA, DGB, EGC, FAC, GBD, and GCE (cf. Figure 1). The errors depending on height corresponded to errors with next chords in this order. For example, if the correct answer is CEG, errors depending on height occurred when a participant answered 'CFA' or 'BDG.'

Errors depending on chroma. Errors depending on chroma reflected confusions of chords that had categorically identical component tones separated by height. The nine white chords were classified into three groups according to component tones: the chords consisting of C, E, and G (CEG, EGC, GCE), the chords consisting of F, A and C (CFA, ACF, and FAC) and the chords consisting of G, B, and D (BDG, DGB, and GBD). Errors depending on chroma corresponded to confusion within a group of the same tones. An example of this would be when the correct answer was CEG, a participant answered 'EGC' or 'GCE.'

Errors of no answer. These errors were mainly classified as responses consisting of participants giving no answer; this could include guesses, unclassifiable conclusions and general mistakes. In general, these were incorrect responses that could not be classified as errors depending on either height or chroma.

Transitions of three types of errors.

Figure 5 illustrates profiles of all three types of the above errors over training weeks for one participant (case 12 only; other cases appear in Appendix 1). The first leftmost vertical axis represents the number of acquired chords (as defined previously) whereas the rightmost vertical axis represents the percentage of errors over all trials (including trials with correct answers; i.e. 10% means this type of error occurred on 10% of trials). Different line types correspond respectively to the different types of errors.

Table 2 shows the first appearance of the errors depending on chroma (i.e., as the number of weeks from training onset) and the number of the chords when the errors depending on chroma first appeared. Table 2 also shows the average percentage (over weeks) of each of the three errors. Participants with previous musical training (cases 4, 7, 11, 13, 16, 18, and 20) have no common distinguishing feature(s) with regard to the distribution of the three types of errors.

These error profiles revealed great individual differences. The features common to all cases are described in the following sections, per the type of error.

Errors depending on height. In the majority of cases, the most common errors involved confusion due to pitch height. In each of the 17 cases (with exceptions in cases 2, 4, 7, 13, and 18), the percentage of the errors depending on height was the greatest of the three kinds of errors. Errors depending on height were observed throughout training and were especially common at the beginning of training. We also found a tendency for the errors depending on height to decrease following the appearance of the errors depending on chroma. This pattern emerged as an alternation of error types; it was observed in 20 cases, all but cases 2 and 9. The two latter cases both exhibited unusual features. In case 2, the errors depending on height remained at a low rate throughout the training. In case 9, the errors depending on height remained at a high level until the end of training.

Errors depending on chroma. Every participant made errors depending on chroma. These errors tended to occur when new chords could not be added. Table 2 shows the number of acquired chords at the time the errors depending on chroma first appeared; it shows that these errors appeared at four chords in one participant, at five chords in five participants, at six chords in 10 participants, at seven chords in three participants, and at eight chords in three participants. The errors depending on chroma tended to first appear at around six chords. The chord numbers corresponding to the first appearance of errors depending on chroma also substantially matched the chord numbers associated with the onset of the doldrums. The percentage of the errors depending on chroma was generally lower than the percentage of the errors depending on height; however, the percentages of the errors depending on chroma tended to increase as training progressed. This tendency appeared in 16 participants of the 22 participants (all but cases 2, 7, 10, 17, 18, and 20).

Errors of no answer. The remaining errors differed greatly with participant. For instance, one participant (case 20) made very few no answer errors, whereas others (cases 2 and 13) made a majority of these errors. The frequency of these errors appears to depend on an individual's temperament.

According to the above description, the common features discovered across all participants appeared related to two kinds of errors, namely those depending on height and chroma. The errors depending on height were more frequent early in training, decreasing as training progressed. By contrast, the errors depending on chroma appeared at the same chord number as the onset of the doldrums, and seemed to gradually increase as if they traded off with the errors depending on height.

Discussion

The results of this study reveal three important points. The first is that this research provides convincing evidence that the CIM is an effective technique for establishing AP. It also shows that AP is an ability that can be acquired through intentional training. There has been no previous report of success in the development of AP for adults or children using a direct training method for AP acquisition. The results of this study are the first to show this in children. As such they provide direct support for an early-learning theory of AP. In this study, all of the 22 young participants who completed the training acquired AP. Because it cannot be assumed that all of these participants are gifted, we can reject an explanation holding that AP is the result of a special talent. Instead, this study indicates that training or experience in early childhood can result in the development of AP. Vitouch (2003) pointed to the possibility that children showing signs of AP in early childhood receive access to early music training. This idea represents an inverted causality in that the children would have started music training because they already had AP or signs of AP. The present study ensured that the participants did not have AP previous to their participation. Children aged 6 years or less can acquire AP minimally by executing procedures associated with the CIM. This entailed a schedule that required daily training in chord identification; it involved about 100 brief training trials distributed throughout a single day followed by a few years of practice. Nevertheless, it is not possible to conclude that this method is the only method that can lead to the acquisition of AP. It is quite possible that other methods are also effective, particularly if they include sufficient practice at the appropriate ages.

A second major point can be drawn from this research. The nature of chord identifications, which occurs over weeks of training, documents an interesting progression of learning during acquisition of AP skills. Using this longitudinal paradigm we could track the evolution of three kinds of errors people make while learning to label individual pitches. Changes over time, shown in individual error profiles, suggest a particular strategy. For instance, the errors depending on height are caused by confusions of chords with tone frequencies within similar regions of the pitch height dimension, independently of chroma. In contrast, the errors depending on chroma appear to be based on only tone chroma and not on height. Errors of no answer are taken to mean there is confusion based on neither height nor chroma.

The profiles of these different errors over time suggest that children shift their strategies as they learn to perceive chords. At the beginning of training, because most errors involved confusions based on height, people appear to initially attend to height, and use it as a basis for responding. Furthermore, early in training the number of the chords was so limited that attending to height functions as a successful strategy for identifying chords. However, as the number of acquired chords approaches or exceeds six (or thereabouts), a strategy based on height alone will necessarily reach a ceiling. Consistent with this idea, a number of errors were observed in this time period indicating a halt in the increase of the number of chords learned. Indeed, this explains the plateau observed in most participants' learning profiles. The doldrums plateau apparently reflects a floundering height strategy. At this point, participants are forced to seek a more effective strategy than one based upon height. Consequently, they finally began to pay attention to chroma. The appearance of the errors depending on chroma is consistent with the idea that participants began to display a growing awareness of chroma. Finally, following the doldrums period, a cognitive strategy depending on height began to integrate with a strategy based on chroma. However, this process also opened up the possibility of conflicts between the two strategies; this conflict is evident in increased errors following the doldrums. From this perspective, participants must eventually acquire a strategy covering both height and chroma. The perfect identification of nine white chords indicates the two strategies have been successfully integrated because both chroma and height are necessary to identify nine white chords with perfect accuracy. Therefore the process of acquiring AP involves a change that incorporates chroma into a strategy originally dependent on height as the dominant cue. To be clear, evidence for these changes is observed only when considering cognitive processes involved with learning as stipulated by the CIM. It remains unclear whether or not this analysis extends to the progress of learning which uses other methods.

A third important issue concerns implications of the present findings for training methods that may be likely to provide the greatest success in instantiating AP skills. Generally, it appears that tasks in which chroma is a more valid – that is, useful – cue than height will encourage participants to rely upon chroma information. For instance, the requirement to identify certain chords, given the CIM, meets a goal of enforcing attention to chroma. In fact, the chords used in the CIM were close in register, namely similar in height regions while they differed in chroma. For instance, correct identification of the first chord 'CEG' and the second chord 'CFA' required discriminations among chords that were similar in height but different in chroma because these two chords contain quite different tones. This sort of differentiation made it very difficult for young children to decide whether 'CEG' or 'CFA' was higher in height. Adding a chord that was similar to the preceding chords in height, yet different in chroma, was designed to call participants' attention to the relevant cue of chroma.

A broader implication of this is pertinent to the fact that AP is not a commonly observed trait. One reason for this is that it is simply fairly difficult to spontaneously pay attention to chroma even for children who are young enough to acquire AP. If it were easy to pay attention to chroma – that is, without intentional training – then the percentage of AP possessors would undoubtedly be much higher than it is. Music experience in young childhood, then, can be considered only a necessary but not sufficient condition for development of AP. This is because what appears to be necessary is the intention to allocate attention to chroma and to incorporate chroma into a broader strategy for the acquisition of AP.

The idea that training should aim for the identification by chroma explains why the identification of chords ensures the acquisition of AP. A suite of chords that assures AP should be the minimum number of chords that participants fail to identify without referring to chroma. In other words, chroma features need to be the sole differentiation feature in choice tasks. In this way, participants can be forced to attend to and use chroma to perfectly identify a suite of chords which are similar in height demanded by the CIM. Therefore perfect identification of chords during training ensures the use of chroma.

Finally, three remaining observations concern implications and limits of this study. First, the processes leading to the acquisition of AP should be generalized in the future. The procedural process described (in detail) in this study depended upon a specific training method, the CIM. This method was adopted for two reasons. The percentage of persons reportedly acquiring AP by this method was over 90% and procedural details of training were easily learned and applied. However, these results may be limited to the CIM; that is, they may not be directly applicable to the general process of AP acquisition. In the future, it will be necessary to examine whether similar acquisition processes are observed by other training methods or not.

Second, this research implies that we should investigate phenomena concerning the critical period. Eguchi claimed that no child older than 8 years old could acquire AP through her method. Is this true? If so, what is lost after we reach the age of 8? We need to investigate learning in children who have passed the critical period to ascertain why they cannot acquire AP. This may offer a key to understanding what the necessary conditions are for acquisition of AP. Based on the results of this study the author speculates that the attention to chroma is needed to acquire AP and that this decreases as children get older; however, this remains to be tested.

Third, individual differences need to be examined. Some previous studies have pointed to genetic predispositions as influencing the development of AP due to the remarkable differences in the percentage of AP possessors among racial groups. For instance, Gregersen et al. (2000) reported that the percentage of AP possessors in Asian students was higher than that in non-Asian students, exclusive of early music training. The present study suggests that early music training was an important factor in the development of AP because every participant could acquire AP through the explicit training. However, the possibility of a genetic predisposition in AP cannot be denied. In this study, 22 participants showed individual differences in the lengths of the periods of required training, the transitions of the number of chords and the percentages of various types of errors, although they were trained by an identical method. These differences cannot be explained by the fact that participants had different trainers. Nor do the observed differences appear to correlate with age, gender, and previous music experience of participants; thus potential causes of such differences remain unclear. Although it is overly simplistic to attribute these differences to genetic predisposition, genetic factors cannot be entirely eliminated as one source of individual differences. Chin (2003) pointed to the possibility that a tendency to develop AP was influenced by individual differences in cognitive style. Cognitive style is also a potential candidate for the explanation of individual differences in the processes of acquiring AP.

The main purpose of this study was to train children to acquire AP through the use of a certain method that has been reported as effective. This research is the first attempt to extensively document the results of an intensive AP training method. Future studies are required to examine other factors that influence the processes of acquiring AP, such as alternate types of training, the age of participants, and individual differences.

Acknowledgements

I would like to thank Dr. Akimichi Omura (emeritus professor of Tokyo University), who guided this study. And I wish to express my gratitude to Dr. Jun-ichi Abe (emeritus professor of Hokkaido University) for reading the draft and making a number of helpful suggestions. This study owes much to the cooperation of the students of Ichionkai Music School and their families.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

Bachem, A. (1937). Various types of absolute pitch. *Journal of the Acoustical Society of America*, *9*, 146–151.

Bachem, A. (1955). Absolute pitch. *Journal of the Acoustical Society of America*, *27*, 1180–1185.

Baharloo, S., Johnston, P. A., Service, S. K., Gitschier, J., & Freimer, N. B. (1998). Absolute pitch: An approach for identification of genetic and nongenetic components. *American Journal of Human Genetics*, *62*, 224–231.

Brady, P. T. (1970). Fixed-scale mechanism of absolute pitch. *Journal of the Acoustical Society of America*, *48*, 883–887.

Chin, C. S. (2003). The development of absolute pitch: A theory concerning the roles of music training at an early developmental age and individual cognitive style. *Psychology of Music*, *31*, 155–171.

Cohen, A. J., & Baird, K. (1990). Acquisition of absolute pitch: The question of critical periods. *Psychomusicology*, *9*, 31–37.

Crozier, J. B. (1997). Absolute pitch: Practice makes perfect, the earlier the better. *Psychology of Music*, *25*, 110–119.

Cuddy, L. L. (1968). Practice effects in the absolute judgment of pitch. *Journal of the Acoustical Society of America*, *53*, 1737–1739.

Cuddy, L. L. (1970). Training the absolute identification of pitch. *Perception & Psychophysics*, *8*, 265–269.

Deutsch, D., Dooley, K., Henthorn, T., & Head, B. (2009). Absolute pitch among students in an American music conservatory: Association with tone language fluency. *The Journal of the Acoustical Society of America*, *125*, 2398–2403.

Deutsch, D., Henthorn, T., Marvin, E., & Xu, H. (2006). Absolute pitch among American and Chinese conservatory students: Prevalence differences, and evidence for a speech-related critical period (L). *Journal of Acoustical Society of America*, *119*, 719–722.

Eguchi, K. (1991). *Zettai onkan program* [An absolute pitch program]. Tokyo, Japan: Zen-on Gakufu Shuppan (in Japanese).

Gregersen, P. K., Kowalsky, E., Kohn, N., & Marvin, E. W. (1999). Absoute pitch: Prevalence, eth-

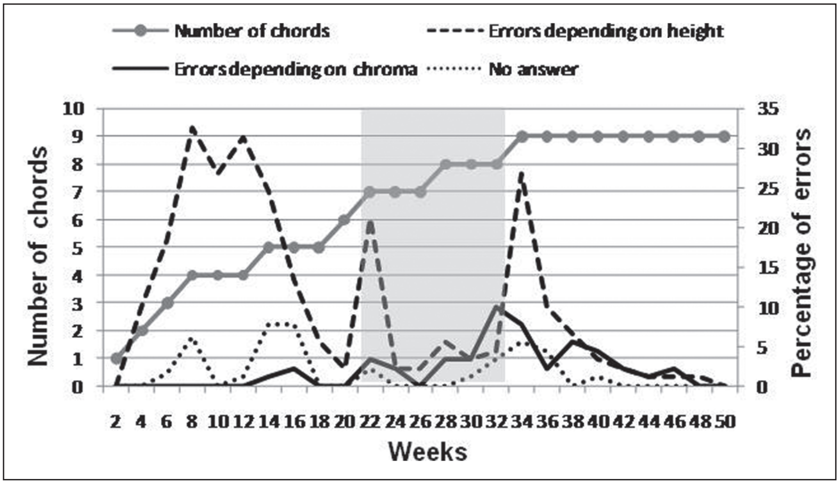
nic variation, and estimation of the genetic component. *American Journal of Human Genetics*, *65*, 911–913.
Gregersen, P. K., Kowalsky, E., Kohn, N., & Marvin, E. W. (2000). Early childhood music education and predisposition to absolute pitch: Teasing apart genes and environment. *American Journal of Medical Genetics*, *98*, 280–282.
Hsieh, I. -H., & Saberi, K. (2008). Language-selective interference with long-term memory for musical pitch. *Acta Acustica united with Acustica*, *94*, 588–593.
Hsieh, I. -H., & Saberi, K. (2010). Language-selective interference with long-term memory for musical pitch. In S. M. Demorest, S. J. Morrison, & P. S. Campbell (Eds.), *Proceedings of the 11th international conference on music perception and cognition (ICMPC 11)* (pp. 634–638). Seattle, WA: ICMPC.
Levitin, D. J., & Rogers, S. E. (2005). Absolute pitch: Perception, coding, and controversies. *Trends in Cognitive Sciences*, *9*, 26–33.
Meyer, M. (1899). Is the memory of absolute pitch capable of development by training? *Psychological Review*, *6*, 514–516.
Miyazaki, K., & Ogawa, Y. (2006). Learning absolute pitch by children: A cross-sectional study. *Music Perception*, *24*, 63–78.
Mull, H. K. (1925). The acquisition of absolute pitch. *American Journal of Psychology*, *36*, 469–493.
Profita, J., & Bidder, T. G. (1988). Perfect pitch. *American Journal of Medical Genetics*, *29*, 763–771.
Rakowski, A., & Miyazaki, K. (2007). Absolute pitch: Common traits in music and language. *Archives of Acoustics*, *32*(1), 5–16.
Revesz, G. (1913). *Zur grundlagen der tonpsychologie* [The basics of sound psychology]. Leipzig, Germany: Veit.
Russo, F. A., Windell, D. L., & Cuddy, L. L. (2003). Learning the 'special note': Evidence for a critical period for absolute pitch acquisition. *Music Perception*, *21*, 119–127.
Saffran, J. R. (2003). Absolute pitch in infancy and adulthood: The role of tonal structure. *Developmental Science*, *6*, 35–47.
Saffran, J. R., & Griepentrog, G. J. (2001). Absolute pitch in infant auditory learning: Evidence for developmental reorganization. *Developmental Psychology*, *37*, 74–85.
Sakakibara, A. (1999). A longitudinal study of a process for acquiring absolute pitch. *Journal of Educational Psychology*, *47*, 19–27 (in Japanese).
Sergeant, D. C., & Roche, S. (1973). Perceptual shifts in the auditory information processing of young children. *Psychology of Music*, *1*, 39–48.
Stalinski, S. M., & Schellenberg, E. G. (2010). Shifting perceptions: Developmental changes in judgments of melodic similarity. *Developmantal Psychology*, *46*, 1799–1803.
Takeuchi, A. H., & Hulse, S. H. (1993). Absolute pitch. *Psychological Bulletin*, *113*, 345–361.
Vitouch, O. (2003). Absolutist models of absolute pitch are absolutely misleading. *Music Perception*, *21*, 111–117.
Ward, W. D. (1999). Absolute pitch. In D. Deutsch (Ed.), *The psychology of music* (2nd ed., pp. 265–298). San Diego, CA: Academic Press.
Wedell, C. H. (1934). The nature of the absolute judgment of pitch. *Journal of Experimental Psychology*, *17*, 485–503.

Author biography

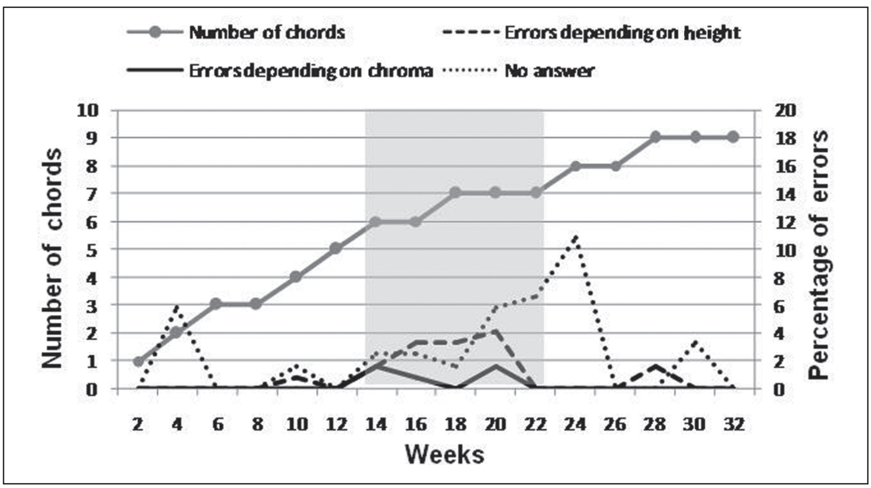
Ayako Sakakibara is an instructor at the Ichionkai Music School and a lecturer at the Department of Psychology, Gakushuin University, Tokyo.

Appendix 1

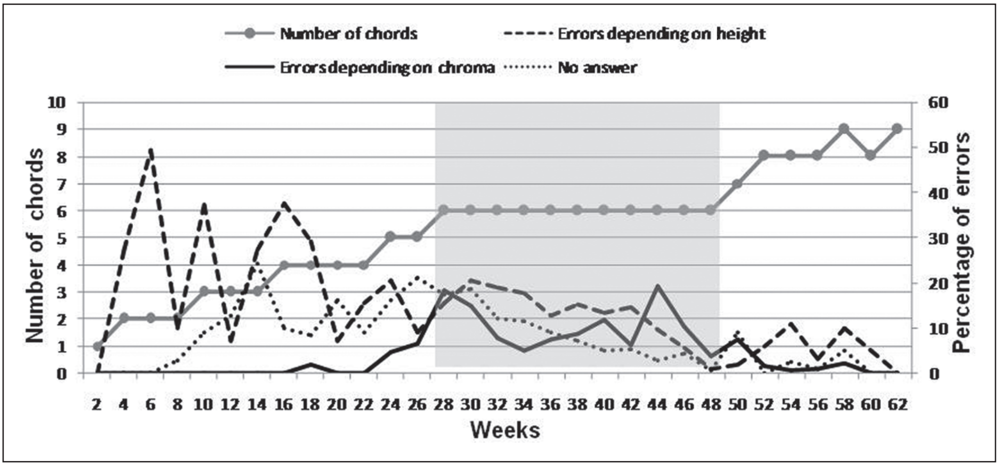
Changes of number of acquired chords and percentage of three types of errors in all cases except for case 12



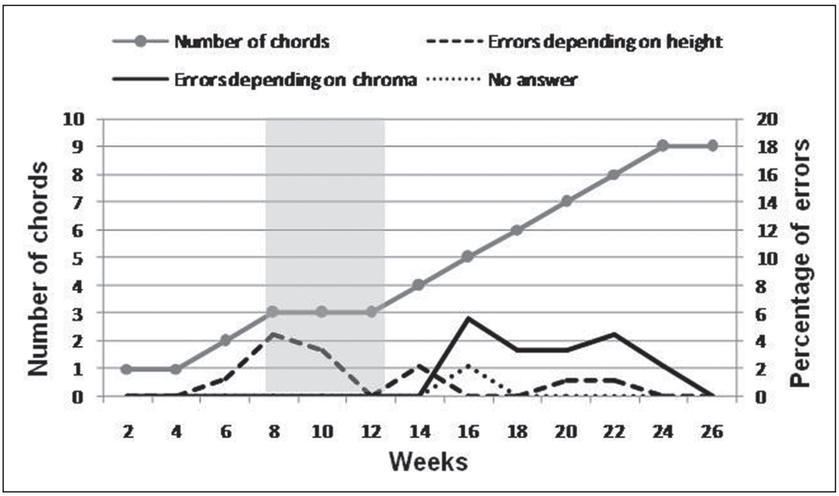
Case 1.



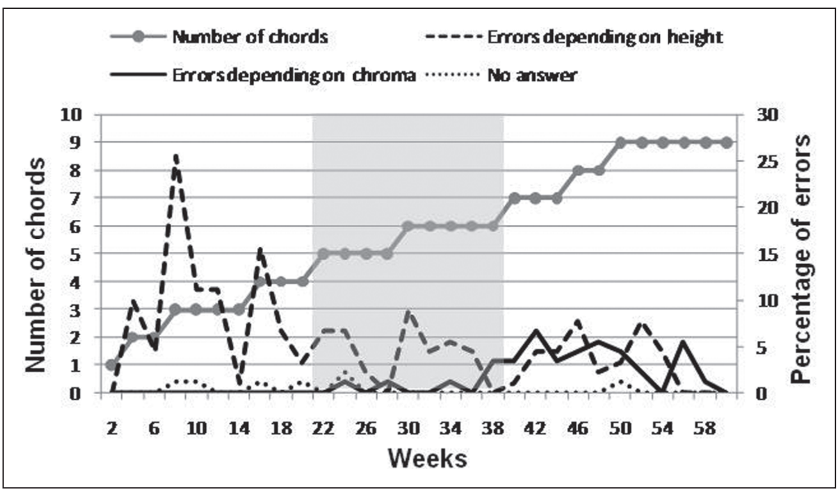
Case 2.



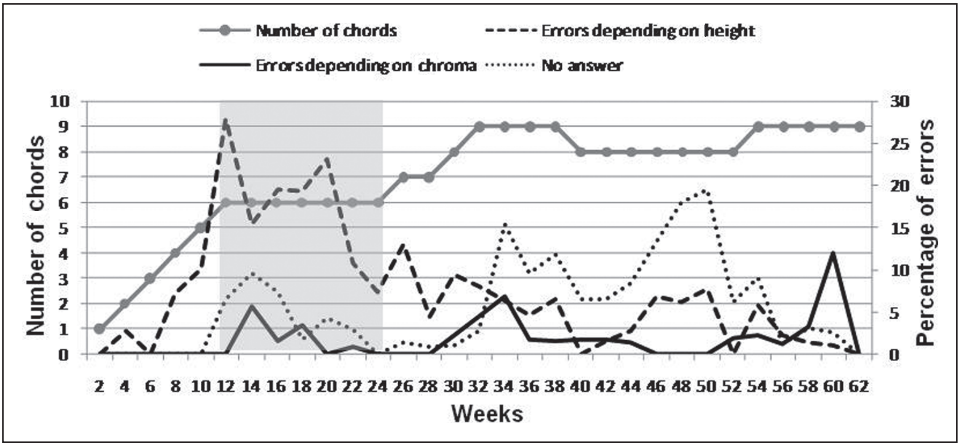
Case 3.



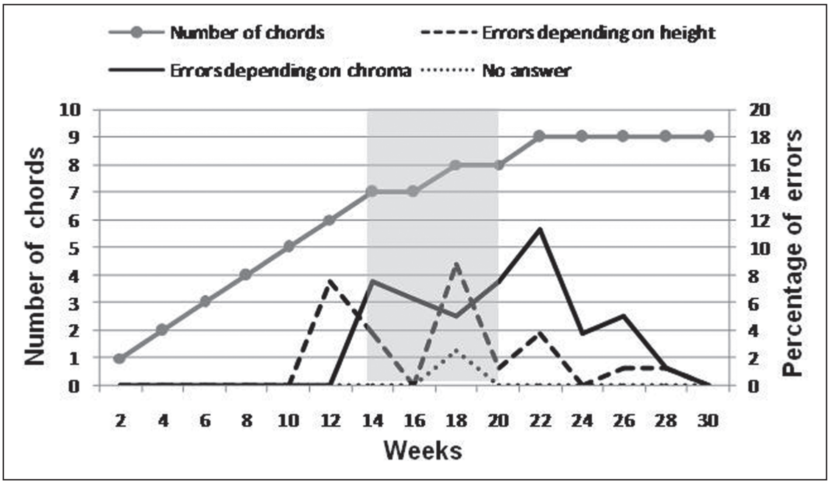
Case 4.



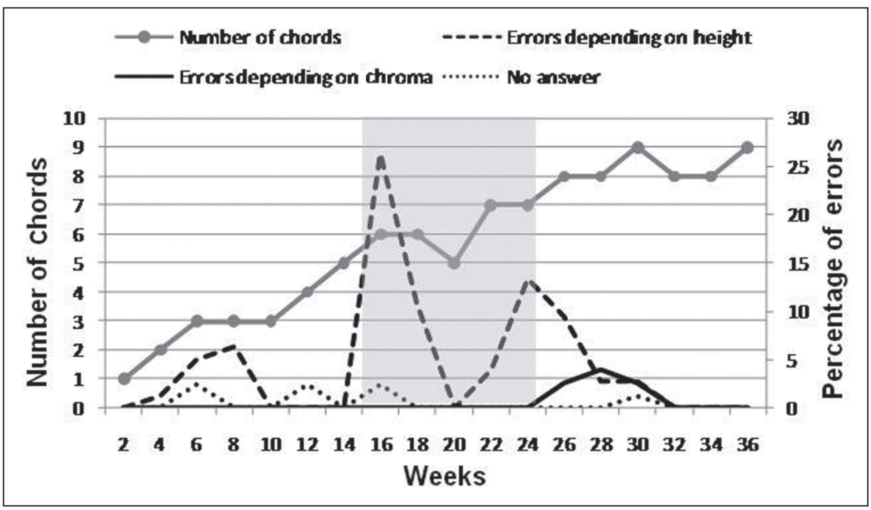
Case 5.



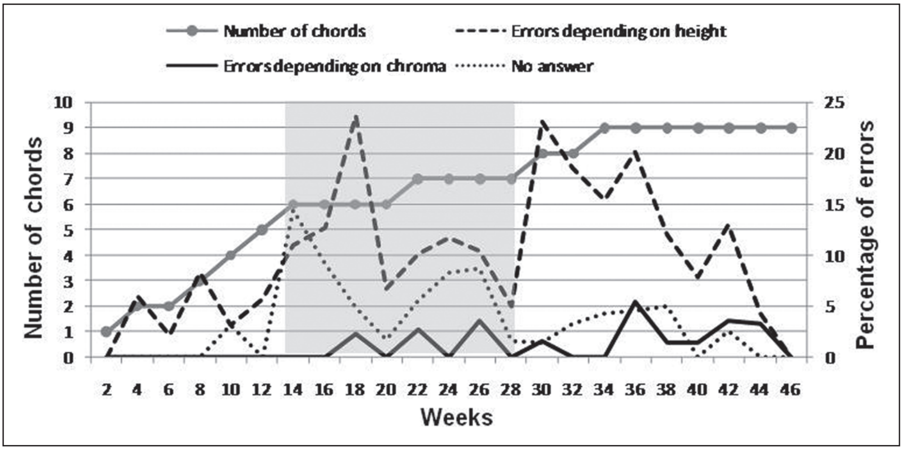
Case 6.



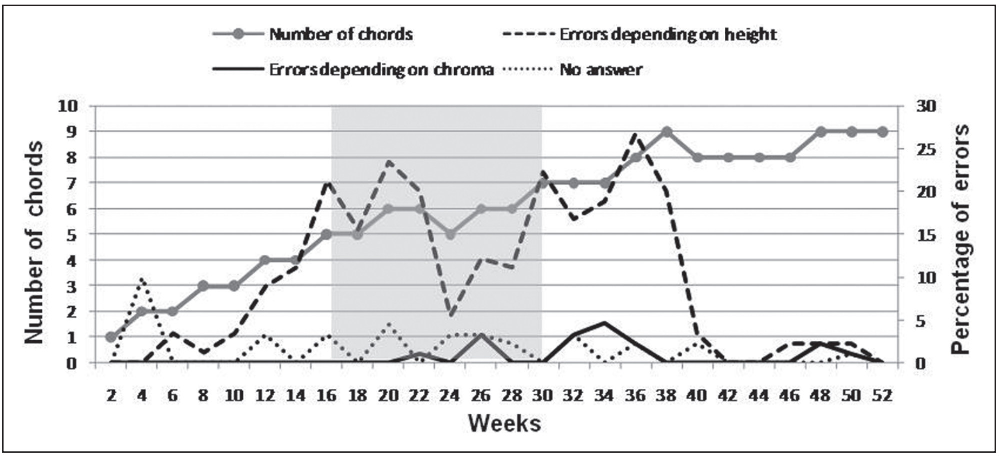
Case 7.



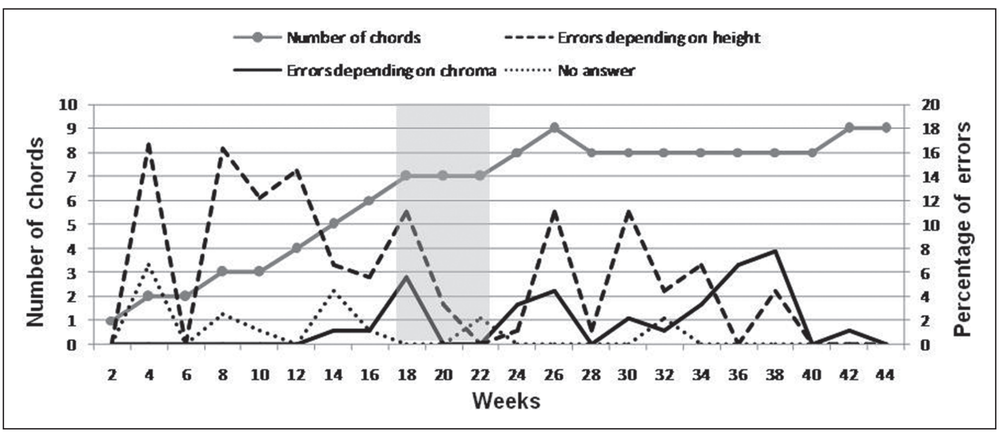
Case 8.



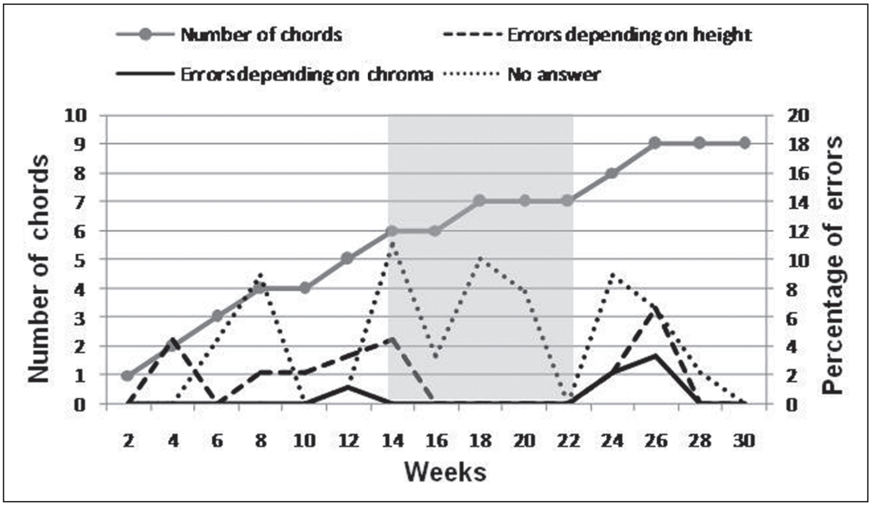
Case 9.



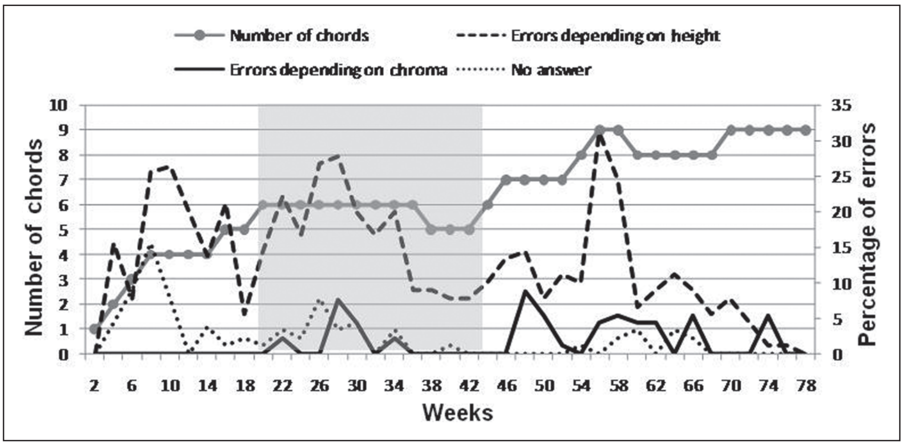
Case 10.



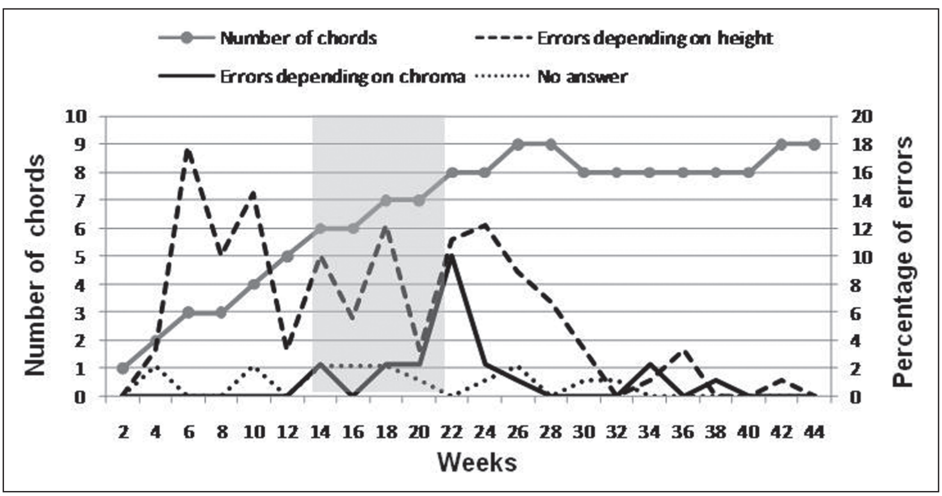
Case 11.



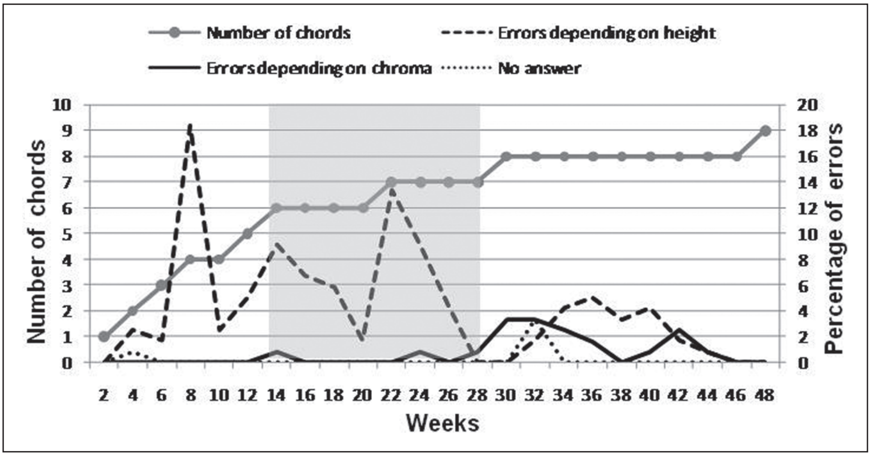
Case 13.



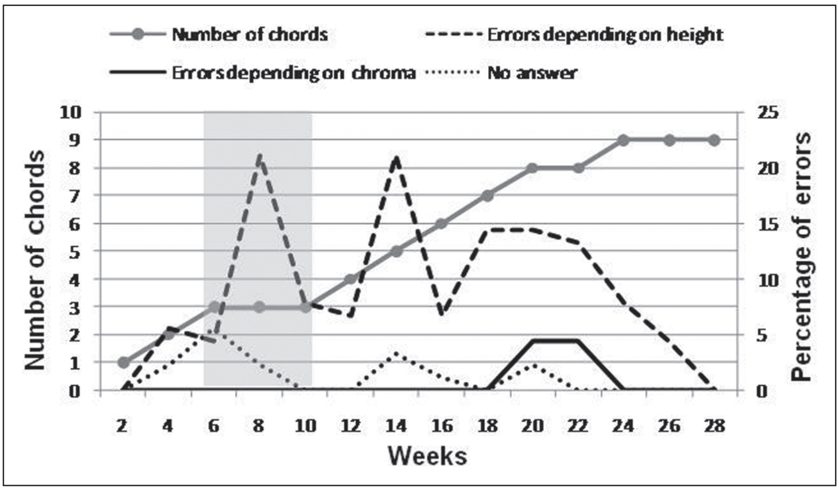
Case 14.



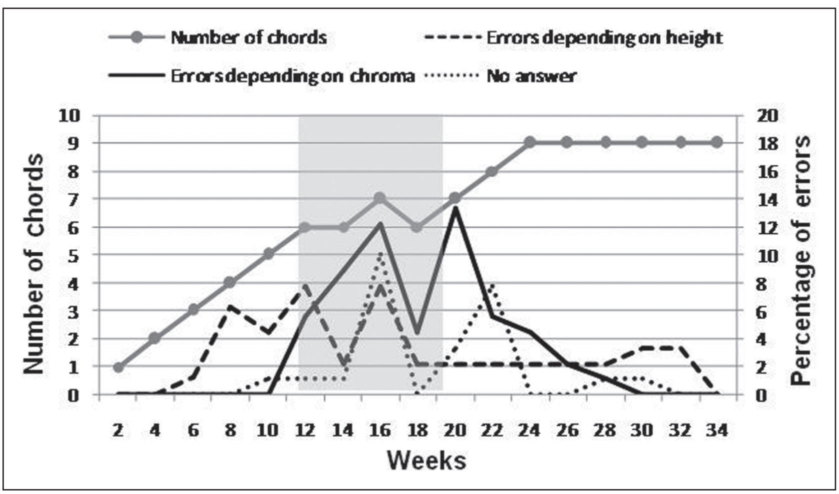
Case 15.



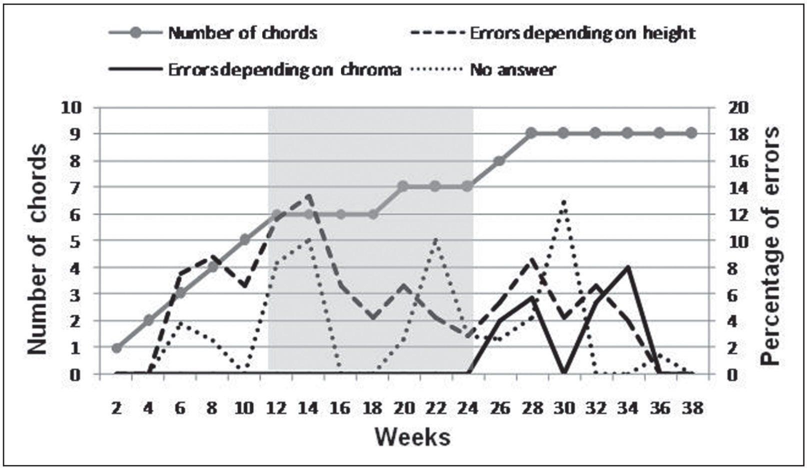
Case 16.



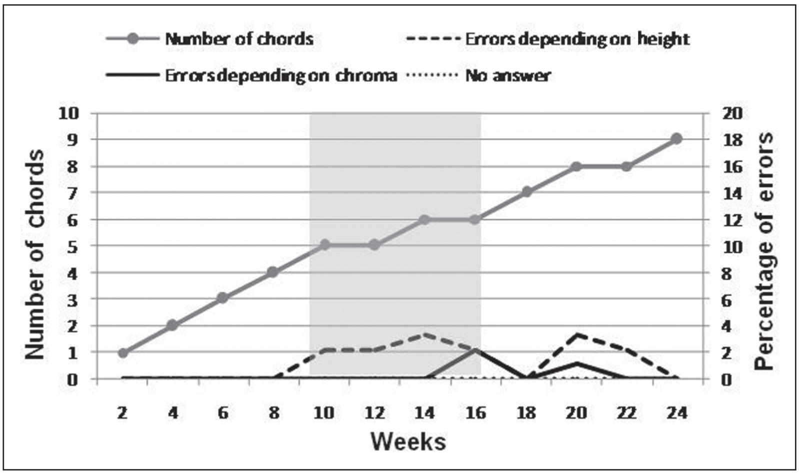
Case 17.



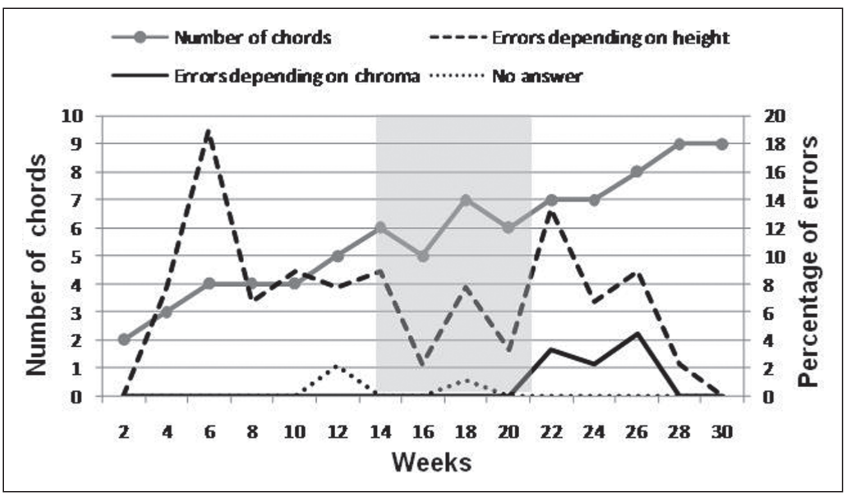
Case 18.



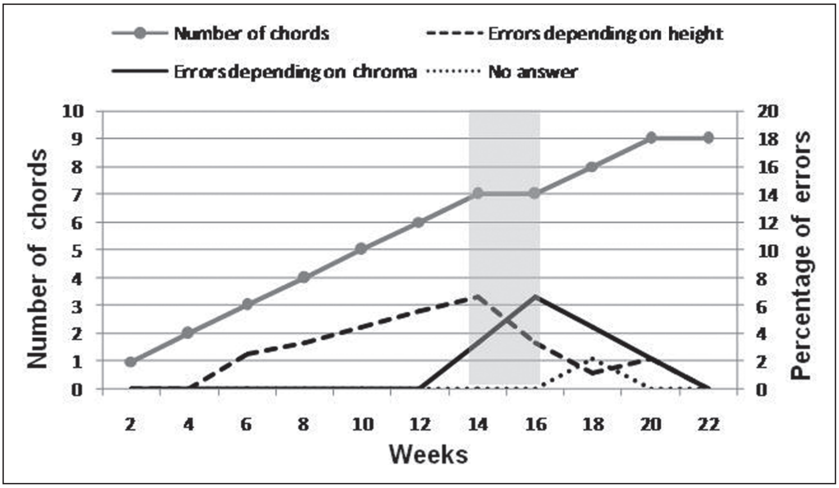
Case 19.



Case 20.



Case 21.


Number of chords
Errors depending on height
Errors depending on chroma
No answer
Number of chords
Percentage of errors
Weeks
10
9
8
7
6
5
4
3
2
1
0
20
18
16
14
12
10
8
6
4
2
0
2
4
6
8
10
12
14
16
18
20
22

Case 22.