Prevalence of absolute pitch: A comparison between Japanese and Polish music students

Ken'ichi Miyazaki[a)]
Department of Psychology, Niigata University, Niigata 950-2181, Japan

Sylwia Makomaska
Institute of Musicology, University of Warsaw, Warsaw 00-927, Poland

Andrzej Rakowski
Fryderyk Chopin University of Music, Warsaw 00-368, Poland

(Received 16 April 2012; revised 18 July 2012; accepted 17 September 2012)

Comparable large-scale surveys including an on-site pitch-naming test were conducted with music students in Japan and Poland to obtain more convincing estimates of the prevalence of absolute pitch (AP) and examine how musical experience relates to AP. Participants with accurate AP (95% correct identification) accounted for 30% of the Japanese music students, but only 7% of the Polish music students. This difference in the performance of pitch naming was related to the difference in musical experience. Participants with AP had begun music training at an earlier age (6 years or earlier), and the average year of commencement of musical training was more than 2 years earlier for the Japanese music students than for the Polish students. The percentage of participants who had received early piano lessons was 94% for the Japanese musically trained students but was 72% for the Polish music students. Approximately one-third of the Japanese musically trained students had attended the Yamaha Music School, where lessons on piano or electric organ were given to preschool children in parallel with fixed-do solfège singing training. Such early music instruction was not as common in Poland. The relationship of AP with early music training is discussed.
 [http://dx.doi.org/10.1121/1.4756956]

PACS number(s): 43.75.Cd [DD] Pages: 3484–3493

I. INTRODUCTION

Absolute pitch (AP) is the ability to identify the names of musical pitch (pitch classes or tone chromas) of isolated tones accurately and quickly without reference to an external standard. It has long been believed that AP is an extremely rare ability, although there have been few systematic studies on the prevalence of AP possession so far. Estimates of AP incidence found in the literature generally emphasize the extreme scarcity of AP possessors, although they vary widely depending on the AP criterion adopted and the measurement method. For example, the prevalence of AP in the general population has been estimated at 1 out of 1500 (Profita and Bidder, 1988) or even less than 1 out of 10 000 (Bachem, 1955). These estimates have been frequently quoted in the literature uncritically to impress readers with the rarity of AP. However, these estimates are not based on any reliable empirical data. Profita and Bidder (1988) did not draw their estimate from empirical data, but simply, quoting their own unpublished observations, reported their estimate as an impression by music teachers who had taught children for many years. Bachem (1955) drew his estimate from his earlier studies (Bachem, 1937, 1940), in which he had observed 123 musicians with varying degrees of AP in the Chicago district and inferred that many more should still exist. He seems to have drawn his estimate of AP probably by contrasting the presumed number of AP possessors by 4×10^6 (the number of people living in Chicago, suburbs, and Urbana) without mentioning how he had sampled his AP possessors from the population. This is an unjustified method for calculating the incidence of AP because Bachem's AP participants were obviously not randomly selected from the entire population but were probably recruited from the musical community. Indeed, it is true that AP is rare among the general population. However, the frequently quoted estimates of the incidence of AP are unreliable because they are improperly calculated from biased samples or are based on anecdotal reports with no explicit criteria.

On the other hand, AP does not appear to be very rare among musicians, because it is closely associated with experience in music. The estimated incidence of AP among musicians in western cultures varies widely from 3% to 15%, probably depending on the differences in AP criteria and sampling methods (Baharloo *et al.*, 1998; Révész, 1946; Wellek, 1938). Further, several studies have reported that the prevalence of AP in musicians is different among people having different ethnic or cultural backgrounds. Gregersen *et al.* (2000) conducted questionnaire surveys of music students in educational institutions in the United States and reported that the proportion of musicians having AP is higher in Asians, particularly in Chinese and Koreans, than in Caucasians. They argued further that these data along with certain genetic indices demonstrated genetic influences in AP. However, their results were based primarily on self-reports, and therefore less convincing. More recently, Deutsch *et al.* (2006)

a)Author to whom correspondence should be addressed. Electronic mail: miyazaki@human.niigata-u.ac.jp

conducted an on-site AP test for music students of China and the United States and obtained more convincing evidence demonstrating a much higher prevalence of AP among Chinese than among Caucasians. Deutsch *et al.* (2006) interpreted this difference as evidence for a close link between AP and tonal languages. In a follow-up study, Deutsch *et al.* (2009) presented evidence for the link, showing that among music students in an American music conservatory, fluent tone-language speakers of East Asian ethnicity showed a higher level of AP performance compared with nonfluent tone-language speakers and non-tone-language speakers. In a series of reports, Miyazaki pointed out that, in present-day Japan, a higher proportion of music students have AP than was previously believed (Miyazaki, 1990). Further, he compared the results of AP identification between the Japanese and Polish music students and demonstrated a higher incidence of AP in Japanese students (Miyazaki, 2007). Accurate AP listeners who scored greater than or equal to 90% in identifying 12 pitch classes accounted for approximately 30% of the Japanese students and 11% of the Polish students. However, these estimates of the AP incidence may have been not very reliable because of an insufficient number of participants and may have been biased toward an overestimation of the AP incidence because the participants were not randomly sampled but were intentionally recruited for investigating AP-related performance.

This study aims to obtain more convincing data to answer the questions of how prevalent AP is among musicians and whether there is any difference in the AP prevalence among different ethnic or cultural groups. To our knowledge, there are currently no reliable data, except for Deutsch *et al.* (2006) and Deutsch *et al.* (2009), to formulate any convincing answers to these questions. Further, AP is not a simple all-or-none phenomenon, and it appears in significantly different ways among AP listeners, quantitatively in accuracy and qualitatively in pattern of AP identification. Therefore, we also examined and compared these aspects of AP between different cultural groups in more detail. For these purposes, we collected data of AP identification from Japanese music majors and musically oriented students and Polish students majoring in music along with data concerning their musical backgrounds.

II. STUDY 1: PREVALENCE OF AP IN JAPANESE MUSIC STUDENTS

A. Method

This study was conducted to obtain an estimate of the AP prevalence and examine aspects of AP among music majors and musically oriented students in Japan. Data were gathered by Miyazaki from Japanese university students attending a class in the liberal arts course at Niigata University. The class was "Cognitive Psychology of Sound and Music" given by Miyazaki, and therefore the students attending this class were generally more musically oriented than the other students. The identical AP identification test was conducted every year to recruit participants for psychological experiments for other purposes. The data were accumulated from 2004 to 2011.

1. Participants

Participants totaled 1298 Japanese undergraduate students. Of these participants, 117 were music majors enrolled in the Faculty of Education, Niigata University. The remaining participants were non-music majors specializing in other different areas (humanities, law, economics, education, sciences, medicine, engineering, and agriculture) and were regarded as random samples from the population of university students in Japan, except that they were more musically oriented, and in general, more experienced in music than the general population because of the specific topics of the class they attended. All participants agreed to take an AP test and received partial course credit for their participation.

2. Stimuli

Test stimuli were sampled piano tones generated from a Kurzweil K1000SE/EXT synthesizer (Kurzweil Music System), which was controlled through a MIDI interface by a Macintosh computer running DIGITAL PERFORMER software (Mark of the Unicorn, Cambridge, MA). They consisted of 60 chromatic pitches over 5 octaves, fundamental frequencies of which spanned the 5-octave range from C2 (65.4 Hz) to B6 (1975.5 Hz) tuned according to equal temperament with A4 = 440 Hz. The test tones were played in a random order with the restriction that successive tones were always different pitch classes separated by greater than 16 semitones to discourage the participants from using relative pitch. The tones were recorded onto a compact disc (CD), and played back on a CD player using a high-quality audio system equipped in the lecture room.

3. Procedure

Participants were tested in a group in the lecture room. The test session began with 10 practice trials in which 10 tones randomly selected in the same way as the test tones were presented, and then 60 test tones followed. There was a 3.0 s interval between the onsets of successive tones, during which participants wrote down a pitch class name for each tone, neglecting its octave position in the numbered blank space on an answer sheet. The test session including practice trials lasted approximately 4 min. For pitch class naming, participants were allowed to use their most familiar pitch-labeling method (musical pitch names, e.g., C, C#, D, etc., or solfège syllables, e.g., *do, do#, re,* etc., used in the fixed-*do* system). If the participants could not name the pitch, they were encouraged to guess or fill a slash in the corresponding space. Participants were cautioned against relying on vocal cues and relative pitch. After the test session, participants completed a short questionnaire about their musical experience history.

B. Results and discussion

The percentage of tones whose pitch classes were correctly identified was calculated as an AP score for each participant. Figure 1 shows the 117 music majors' individual AP scores as stacked columns in descending order of AP accuracy. The white and black sections of each column represent

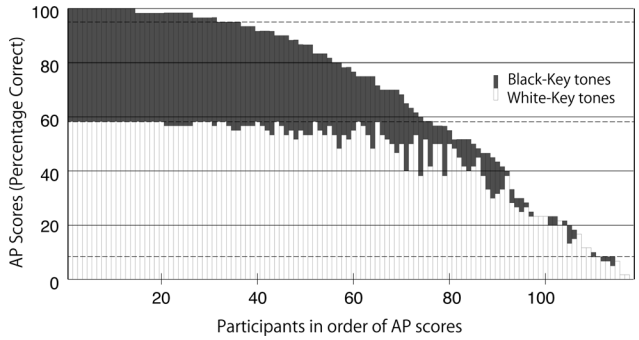

FIG. 1. Distribution of individual AP scores of 117 Japanese music majors as stacked columns in descending order of AP accuracy. The white and black sections of each column represent correct responses to white-key pitches (notes without sharp or flat) and black-key pitches (notes with sharp or flat), respectively. Horizontal dotted lines represent from the top a 95% correct level, a perfect performance for white-key pitches (58.3%), and a chance level (8.3%).

correct responses to white-key pitches (notes without sharp or flat) and black-key pitches (notes with sharp or flat), respectively. Most strikingly, a substantial fraction of the listeners in the music majors group achieved high AP scores; of the 117 music majors, 14 (0.12) performed perfectly, 36 (0.308) exceeded the accurate AP level of 95% correct, and 57 (0.487) exceeded the moderate AP level of 80% correct (see also column 3 of Table I). This result clearly demonstrates that AP is common among Japanese music students. It is particularly worth noting that those who have no AP are in the minority among music students in Japan. The high prevalence of AP in Japanese music students was already suggested in early investigations of Miyazaki (1988, 1990), the results of which were, however, less convincing because in those investigations, to collect data purposefully from AP listeners, participants were recruited from music students who had received early music training and were expected to have AP. As a consequence, there was a self-selection bias in those data probably resulting in a higher prevalence of AP than would be observed in unbiased music students. To avoid the self-selection bias, in the present study, we accumulated data over 8 years from all students who had attended a class in liberal arts education and extracted those who enrolled in the music course as music majors. Therefore, the present study provides more convincing evidence for the prevalence of AP in Japanese music students.

In contrast to the music majors, substantially fewer non-music majors had AP, as shown in Fig. 2. This is not surprising, because fewer non-music majors had received early music training, which is assumed to be required to acquire AP [Miyazaki and Ogawa (2006); see for review, Takeuchi and Hulse (1993); Ward (1999)]. Of the 1163 non-music majors, 21 (0.018) performed perfectly, 42 (0.036) exceeded the accurate AP level of 95% correct, and 91 (0.078) exceeded the moderate AP level of 80% correct (see also column 4 of Table I). However, these percentages of AP are still notably high, given that these participants were non-music majors and in comparison to the extreme rarity of AP among the general population, as frequently mentioned in the AP literature.

Another feature of the distribution pattern is a differential accuracy in identifying white-key and black-key pitches. White-key pitches were identified more correctly than black-key pitches. Because there are seven white-key and five black-key pitch classes in an octave, the perfect score for white-key pitches is 58.3%, as shown by a dotted line in Figs. 1 and 2. More participants among both the music majors and the non-music majors achieved perfect or near perfect performance for white-key pitches than for black-key pitches.

The response pattern across different pitch classes was further examined in more detail. In this analysis, all participants, with music majors and non-music majors combined ($n = 1280$), were classified into six groups depending on AP accuracy level: AP 1 ($n = 78$, 95% correct or higher), AP 2 ($n = 70$, 95%–80% correct), AP 3 ($n = 99$, 80%–60% correct), AP 4 ($n = 112$, 60%–40% correct), AP 5 ($n = 265$, 40%–20% correct), and AP 6 ($n = 656$, lower than 20% correct). The AP 1, AP 2, and AP 3 groups may be called accurate, moderate, and inaccurate, respectively. The number of music majors and non-music majors for each group is shown in the third and fourth columns of Table I, respectively. Average AP scores are presented as a function of pitch classes in the order of tones on the circle of fifths in Fig. 3, demonstrating that AP scores differ markedly among pitch classes. Most prominent is the difference in accuracy between white- and black-key pitches, as summarized in Table I. AP 1, a group of perfect and near perfect AP listeners, showed a high performance level across all pitch classes. The advantage of white-key pitches is seen more clearly in the AP 3, 4, and 5 groups. We performed a two-way mixed-design analysis of variance [(ANOVA), with pitch class category as the within-subject factor and AP accuracy as the between-subject factor]. The main effect of pitch class category (white key vs black key) was significant [$F(1, 1274) = 2899.4$, $MS_e = 79.05$,

TABLE I. AP groups and AP scores (Japanese students).

		n (cumulative proportion)		Average score (SD)	
Group	Range of AP scores	Music majors	Non-music majors	White-key pitch classes	Black-key pitch classes
AP 1	95–100	36 (0.308)	42 (0.036)	99.3 (1.6)	97.1 (3.7)
AP 2	80–95	21 (0.487)	49 (0.078)	93.0 (5.3)	79.9 (10.5)
AP 3	60–80	17 (0.632)	83 (0.150)	84.3 (9.9)	45.5 (14.8)
AP 4	40–60	18 (0.786)	93 (0.230)	70.1 (10.9)	19.0 (13.7)
AP 5	20–40	13 (0.897)	252 (0.446)	40.5 (7.0)	7.7 (7.5)
AP 6	0–20	12 (1.000)	644 (1.000)	17.7 (30.3)	2.0 (3.6)
Sum		117	1163		

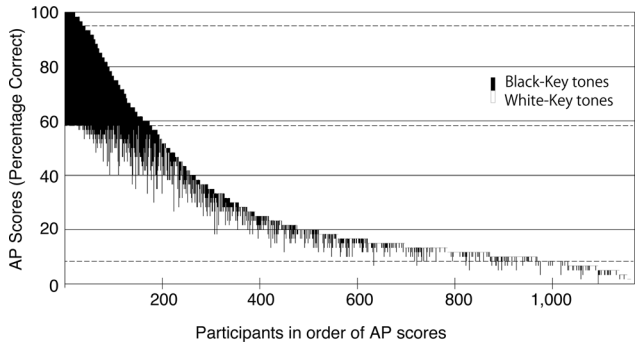

FIG. 2. Distribution of individual AP scores of 1163 Japanese non-music majors as stacked columns in descending order of AP accuracy. The white and black sections of each column represent correct responses to white-key pitches (notes without sharp or flat) and black-key pitches (notes with sharp or flat), respectively. Horizontal dotted lines represent from the top a 95% correct level, a perfect performance for white-key pitches (58.3%), and a chance level (8.3%).

$p < 0.001$, $\eta_p^2 = 0.695$], and the interaction of pitch class category by AP accuracy was also significant [$F(5, 1274) = 271.6$, $MS_e = 79.05$, $p < 0.001$, $\eta_p^2 = 0.516$], indicating that the difference between pitch class categories was dependent upon AP accuracy. *Post hoc* analyses of the interaction revealed a significant advantage of white-key pitches over black-key pitches for all AP groups ($p < 0.001$) except for the most accurate AP 1 group ($p = 0.135$). Among the white-key pitches, the C note was most accurately identified for all AP groups except for the AP 1 group. This was most clearly demonstrated by participants of the AP 5 group who correctly identified C 66% of the time, the other white-key pitches approximately 40%, and the black-key pitches only 6%–9%. A two-way ANOVA with pitch class and AP accuracy as factors revealed the significant main effect of pitch class [$F(11, 14014) = 454.9$, $MS_e = 0.74$, $p < 0.001$, $\eta_p^2 = 0.263$] and the significant interaction of pitch class by AP accuracy [$F(55, 14014) = 45.80$, $MS_e = 0.74$, $p < 0.001$, $\eta_p^2 = 0.152$]. A subsequent analysis of the interaction showed that the simple main effect of pitch class was significant for all AP groups ($p < 0.001$) except for AP 1. Separate multiple comparisons with Bonferroni correction showed that, among the white-key pitches, the C note was more accurately identified than other notes for all AP groups except for the AP 1 group ($p < 0.05$), while there was no significant difference among the white-key pitches for the AP 2 group.

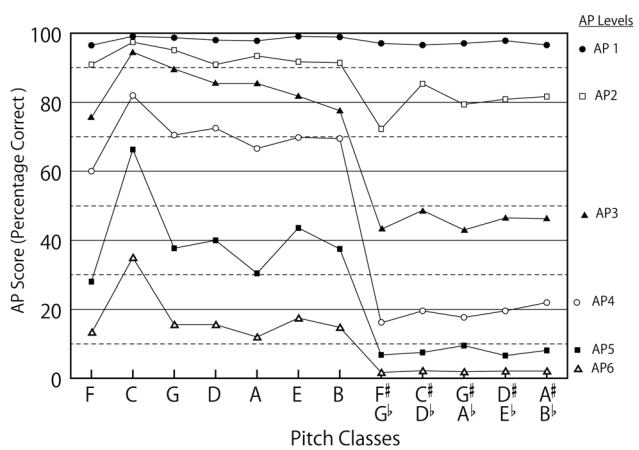

FIG. 3. Averaged AP scores of the Japanese participants in groups of different AP levels as a function of pitch classes arranged in the order of tones on the circle of fifths.

The advantage of the white-key pitches over the black-key pitches and of the C note over the other white-key notes in AP identification is consistent with previous findings (Miyazaki, 1990; Takeuchi and Hulse, 1991). This is assumed to be related to a differential time course of AP acquisition for the white-key and the black-key pitches in childhood. In typical piano lessons for children, AP for the white-key notes is presumably more easily established than that for the black-key notes, because piano lessons usually begin with practicing musical scales and pieces in the C-major key, and their earlier introduction makes it easier to learn the white-key notes than the black-key notes. Actually, in one sample of children who were taking piano lessons in a music school for children, Miyazaki and Ogawa (2006) found that AP development for the black-key pitches begins at approximately age 6, about 2 years behind that for the white-key pitches. If the most effective period for acquiring AP is between ages 3 and 6 years (Takeuchi and Hulse, 1993), AP acquisition for the black-key notes is more difficult than that for the white-key notes, because the sensitive period for learning AP ends at approximately the time when the black-key notes are introduced in piano lessons.

The participants' music background surveyed by the questionnaire is summarized in Table II for the six AP groups in the music majors and the musically trained non-music majors. The non-music majors were divided into those who reported having had music training for 2 years and more outside of the regular school curriculum (musically trained, as shown in Table II) and those who reported having had training for less than 2 years or no training beyond compulsory school classes (musically untrained). Overall, the music majors ($n = 117$) and the musically trained non-music majors ($n = 675$) accounted for 62% of all participants surveyed,

TABLE II. Music background of Japanese students.

Group	*n* (cumulative proportion)	Average age of music training onset (SD)	Average years of music training (SD)	Keyboard instruments	Yamaha
			Music majors		
AP 1	36 (0.308)	4.44 (1.28)	14.65 (1.98)	1.000	0.412
AP 2	21 (0.487)	4.05 (1.02)	15.19 (1.54)	0.952	0.429
AP 3	17 (0.632)	4.38 (1.09)	14.63 (1.63)	1.000	0.188
AP 4	18 (0.786)	5.50 (3.20)	12.44 (3.57)	0.944	0.222
AP 5	13 (0.897)	4.92 (1.50)	13.23 (2.55)	0.846	0.154
AP 6	12 (1.000)	8.67 (5.05)	10.50 (5.09)	0.750	0.250
Total	117	5.03 (2.62)	13.80 (3.03)	0.939	0.307
			Trained non-music majors		
AP 1	38 (0.056)	4.08 (1.26)	12.24 (3.03)	1.000	0.459
AP 2	46 (0.124)	4.57 (1.93)	11.24 (3.31)	0.957	0.478
AP 3	79 (0.241)	4.49 (1.24)	11.41 (3.05)	0.924	0.519
AP 4	84 (0.366)	5.07 (2.03)	10.93 (2.95)	0.964	0.440
AP 5	198 (0.659)	5.50 (1.92)	8.90 (3.60)	0.778	0.273
AP 6	230 (1.000)	6.24 (2.35)	6.59 (3.38)	0.577	0.242
Total	675	5.44 (2.11)	9.01 (3.88)	0.775	0.337

reflecting a distinctive trend in present-day Japan that a considerable portion of children receive early music lessons in private piano classes or music schools outside of the regular school curriculum.

In general, musically trained participants who achieved higher levels of accuracy in identifying AP had begun their music training at an earlier age. A one-way ANOVA revealed that the age of music training onset differed significantly among AP groups of different accuracy levels both for music majors [$F(5, 108) = 7.16$, $MS_e = 5.40$, $p < 0.001$, $\eta_p^2 = 0.249$] and for trained non-music majors [$F(5, 665) = 16.634$, $MS_e = 4.00$, $p < 0.001$, $\eta_p^2 = 0.111$]. *Post hoc* multiple comparisons [Tukey's HSD (Honestly Significant Difference)] for the music majors showed that the AP 1–AP 5 groups did not differ significantly among each other with respect to the age of music training onset, but they did begin music training significantly earlier than the AP 6 group ($p < 0.05$). Comparisons for the trained non-music majors revealed that the AP 1–AP 4 groups did not differ significantly among each other, but did differ significantly from the AP 5 and AP 6 groups. There were moderate correlations between AP scores and the age of music training onset $r = -0.41$ ($p < 0.01$) for the music majors, and $r = -0.33$ ($p < 0.01$) for the trained non-music majors. The average years of music training also significantly differed among AP groups both for the music majors [$F(5, 108) = 6.65$, $MS_e = 7.37$, $p < 0.001$, $\eta_p^2 = 0.235$] and for the trained non-music majors [$F(5, 665) = 48.58$, $MS_e = 11.13$, $p < 0.001$, $\eta_p^2 = 0.268$]. The more accurate the participants were in the AP identification, the longer music training they had received. Multiple comparisons of years of music training (Tukey's HSD, $p < 0.05$) showed, for the music majors, that differences among the AP 1–AP 3 groups were not significant, but there were significant differences between the AP 1–AP 3 groups and AP 6; for the non-music majors, differences among the AP 1–AP 4 groups were not significant, but differences between the AP 1–AP 4 groups and AP 6 and between AP5 and AP 6 were significant.

The second to last column of Table II shows the proportion of musically trained participants who reported having received lessons on a keyboard instrument (mostly piano, but also electronic organ) for 6 years and more. Keyboard lessons may be effective in acquiring AP, because a keyboard instrument makes tones of fixed pitch and supports the fixed-do pitch-naming system. The proportion of participants who had received lessons on a keyboard instrument was generally very large across all AP groups, indicating a large majority of the musically trained Japanese participants having begun their musical lessons on the piano. The proportion tended to be smaller as the AP accuracy decreased. A χ^2 analysis revealed that the proportion of participants having had keyboard training was not homogeneous among the AP groups for the music majors [χ^2 (5) = 12.68, $p < 0.05$] and for the trained non-music majors [χ^2 (5) = 97.74, $p < 0.001$]. In the music majors, the proportion was significantly smaller than the expected value for AP 6 ($p < 0.05$). In the trained non-music majors, it was significantly larger for AP 1–AP 4 and smaller for AP 6 than the expected value ($p < 0.05$).

The last column of Table II displays the proportion of musically trained participants who reported having ever attended the Yamaha Music School, which is the largest private music school in Japan giving children lessons of the piano or electronic organ. This proportion was more than 40% for the top groups. A χ^2 analysis was performed on three combined AP groups (AP 1–2, AP 3–4, and AP 5–6). The results showed that the proportion was significantly different among the AP groups for the music majors [χ^2 (2) = 6.18, $p < 0.05$] and for the trained non-music majors [χ^2 (2) = 33.52, $p = 0.001$]. For the music majors, the proportion of the participants trained at Yamaha was significantly larger for AP 1–2 and smaller for AP 5–6 than the expected value ($p < 0.05$). For the trained non-music majors, the proportion was significantly larger for the AP 1–2 and AP 3–4 and smaller for AP 5–6 groups than the expected value ($p < 0.05$). The proportion of AP participants (AP 1 and AP 2) in those trained by Yamaha was 0.238, significantly larger than that in those trained otherwise (0.145; $p < 0.05$). These results support the view presented in the previous investigation by Miyazaki and Ogawa (2006) that the Yamaha instruction system is effective in children's AP acquisition.

Table III shows the proportion of AP participants and AP scores as a function of the age of onset of music training for the music majors, the musically trained non-music majors, and the untrained non-music majors. AP participants (AP groups 1–3) accounted for a substantial fraction of the music majors and trained non-music majors who had begun music training at the age of six or earlier. In contrast, the proportion of AP was very small for the music majors and trained non-music majors who had begun music training at the age of seven or later. The average AP scores were substantially higher for the participants who had begun training early. A one-way ANOVA showed a significant effect of the age of onset of music training for the music majors [$F(4,$

TABLE III. Age of music training onset and proportion of AP participants for Japanese participants.[a]

		n (proportion of participants)			
Age of music training onset	*n*	AP 1	AP 1 and 2	AP 1–3	Average AP score (SD)
		Music majors			
3 or earlier	28	9 (0.321)	16 (0.571)	20 (0.714)	72.3 (29.9)
4	27	11 (0.407)	17 (0.630)	22 (0.815)	81.2 (20.0)
5	23	4 (0.174)	11 (0.478)	15 (0.652)	69.0 (27.5)
6	26	9 (0.346)	10 (0.385)	13 (0.500)	61.3 (32.7)
7 or later	10	1 (0.100)	1 (0.100)	1 (0.100)	27.2 (28.7)
Total	114	34 (0.298)	55 (0.482)	71 (0.623)	67.3 (31.4)
		Musically trained non-music majors			
3 or earlier	96	15 (0.156)	25 (0.260)	39 (0.406)	50.9 (31.2)
4	143	12 (0.084)	28 (0.196)	61 (0.427)	50.7 (28.6)
5	148	5 (0.034)	17 (0.115)	36 (0.243)	38.4 (26.3)
6	150	3 (0.020)	9 (0.060)	18 (0.120)	29.8 (23.3)
7 or later	134	2 (0.015)	4 (0.030)	8 (0.060)	22.7 (18.5)
Total	671	37 (0.055)	83 (0.124)	162 (0.241)	37.7 (27.9)
		Musically untrained non-music majors			
	488	4 (0.008)	7 (0.014)	10 (0.020)	14.5(12.8)

[a]Seven participants (three of music majors and four of trained non-music majors) were excluded because they did not report their musical experience.

109) = 7.29, $MS_e = 0.08$, $p < 0.001$, $\eta_p^2 = 0.211$] and for the musically trained non-music majors [$F(4, 666) = 30.4$, $MS_e = 0.07$, $p < 0.001$, $\eta_p^2 = 0.155$]. Multiple comparisons (Tukey's HSD, $p < 0.05$) showed that, for the music majors, the 7-year-old-or-later group was significantly poorer in performance than all the other groups; for the trained non-music majors, the 3-year-or-earlier and 4-year groups were significantly better, and the 6-year and 7-year-or-later groups were significantly poorer in performance than all the other groups. All the other pairwise comparisons were not statistically significant. These results provide further convincing evidence to support the previous observations that most of the top AP participants had begun music lessons at between 3 and 6 years old.

There were a small number (10 out of 488, 2%; 4 in AP 1, 3 in AP 2, and 3 in AP3) of AP participants in the untrained group who reported no music training. At first glance, this may seem curious, because the existence of these participants may be interpreted as indicating AP without music training. However, it seems unreasonable that someone who has no music experience would display the musical AP ability. It is more likely that these participants' reports were unreliable or that some kind of music experience during very early childhood they could not recall or during years of kindergarten and elementary school may have led to AP acquisition.

III. STUDY 2: PREVALENCE OF AP IN POLISH MUSIC STUDENTS

A similar study was carried out with Polish music students as participants. The goals of this study were to examine the prevalence of AP, the response pattern as a function of pitch classes, and the relationship between AP performance and the participants' music background, and to compare these features with those of Japanese music students. Although this study was conducted by Makomaska and Rakowski in Warsaw independent of the Japanese study, the data obtained allowed a meaningful comparison of characteristics of AP between Japan and Poland.

A. Method

1. Participants

Participants were 250 Polish music students who were recruited from the Fryderyk Chopin University of Music in Warsaw, Poland [mean age = 21.4 years, standard deviation (SD) = 4.16, range = 18–50). The participants did not include students outside Poland and were unbiased samples representing the population of music students in Poland.

2. Stimuli

Test stimuli were recorded grand-piano sounds played by an experienced pianist using a high-quality recording system. They consisted of 25 pitches over 5 octaves, the fundamental frequencies of which ranged from 65.4 Hz (C2) to 1975.5 Hz (B6) tuned according to equal temperament with A4 = 440 Hz. Each of 12 pitch classes was presented two times in different octaves except for D#, which was presented three times. The test tones were played in a quasi-random order with the restriction that successive tones were always different pitch classes separated by more than an octave to discourage the participants from using relative pitch. The tones were recorded onto a CD and played back on a CD player using a high-quality audio system.

3. Procedure

The AP test was administered to groups of 6–20 participants. There was a 6.0 s interval between the onsets of successive tones, during which participants wrote down a pitch class name or a solfège syllable for each tone on an answer sheet with its octave position neglected. Participants were allowed to use guessing strategies and were cautioned against relying on vocal cues and relative pitch. After the test session, they completed a short questionnaire on their musical experience history.

B. Results and discussion

The distribution of the AP scores of 250 Polish music students is presented in Fig. 4, where the individual AP score of each participant is shown in descending order as a stacked column with the white and black sections of each column representing correct responses to white-key pitches and black-key pitches, respectively. Regarding the accuracy in identification of all pitch classes, a smaller proportion of the Polish music students achieved high scores; of 250 Polish participants, 13 (0.052) performed perfectly, 18 (0.072) exceeded the accurate AP level of 95% correct, and 30 (0.120) exceeded the moderate AP level of 80%. These proportions were markedly smaller than those of the Japanese music students in study 1 (compare with Fig. 1). AP possessors are in a small minority at the Chopin University of Music, and this may well be the case in other music schools at the conservatory level in Western countries, as frequently mentioned in the AP literature.

In contrast to the Japanese music students, most of whom exhibited a fairly high level of performance for white-key pitches as opposed to black-key pitches, the Polish music students exhibited a similar rate of decline in accuracy both for white-key and black-key pitches (compare Fig. 4

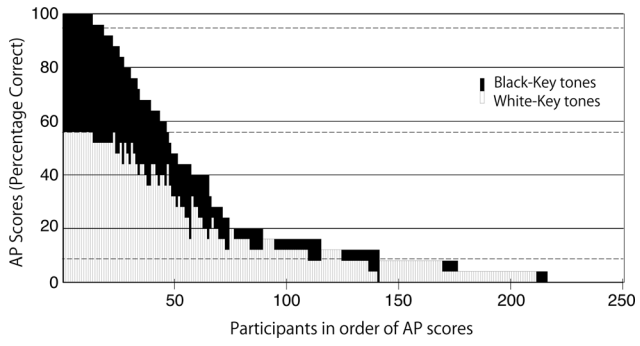

FIG. 4. Distribution of individual AP scores of 250 Polish music students as stacked columns in descending order of AP accuracy. The white and black sections of each column represent correct responses to white-key pitches (notes without sharp or flat) and black-key pitches (notes with sharp or flat), respectively. Horizontal dotted lines represent from the top a 95% correct level, a perfect performance for white-key pitches (58.3%), and a chance level (8.3%).

with Fig. 1). A two-way mixed-design ANOVA was performed with pitch class category as the within-subject factor and AP accuracy as the between-subject factor. The classification of the 250 Polish participants into six groups (AP 1–AP 6) in accordance with the AP scores was carried out in a manner similar to that of the Japanese participants. The analysis revealed a significant main effect of pitch class category (white key vs black key) [$F(1, 244) = 65.1$, $MS_e = 0.006$, $p < 0.001$, $\eta_p^2 = 0.211$], indicating that the advantage of white-key pitches over the black-key pitches was also observed in the Polish participants, but was less pronounced than in the Japanese participants, as reflected in the considerably smaller effect size (η_p^2) for the Polish participants than for the Japanese participants (see also in Table IV). There was also a significant interaction of pitch class category by AP accuracy [$F(5, 244) = 5.83$, $MS_e = 0.008$, $p < 0.001$, $\eta_p^2 = 0.107$], indicating that the difference in accuracy between the white-key and black-key pitches was different among AP groups. *Post hoc* analyses of the interaction revealed a significant advantage of white-key pitches over black-key pitches for the inaccurate AP 3, the borderline AP 4, and the no-AP groups (AP 5 and AP 6) ($p < 0.001$), but the advantage was not significant for either the AP 1 or AP 2 group ($p > 0.05$). Figure 5 shows average AP scores for each AP group of the Polish music students as a function of pitch classes. The identification accuracy varied in a complicated manner among pitch classes. The most accurately identified pitch is D for AP 3, and A for AP 4 and AP 5. The advantage of the C tone in pitch class identification as observed in the Japanese participants was not apparent for the Polish music students.

The average age of music training onset for the Polish participants was 7.84 years (SD = 2.67), which was significantly higher than those of the Japanese music majors ($M = 5.03$ years, SD = 2.62) [$t(362) = 9.38$, $p < 0.001$] and even the Japanese trained non-music majors ($M = 5.44$ years, SD = 2.11) [$t(919) = 14.25$, $p < 0.001$]. However, the average years of music training for the Polish participants was 13.60 years (SD = 4.23), which was approximately equal to that of the Japanese music majors ($M = 13.80$ years, SD = 3.03) [$t(362) = 0.46$, $p = 0.646$]. The correlation between AP accuracy and the age of music training onset was also observed for the Polish participants, but in a less obvious manner than for the Japanese participants. A one-way ANOVA revealed that the age of music training onset was significantly different among AP groups of different accuracy [$F(5, 244) = 5.52$, $MS_e = 6.53$, $p < 0.001$, $\eta_p^2 = 0.102$]. *Post hoc* multiple comparisons (Tukey's HSD) showed that the age of music training onset was significantly different ($p < 0.05$) between the top three AP groups AP 1–AP 3 and the no-AP group AP 6. There was a correlation between the AP score and the age of music training onset, $r = -0.317$ ($p < 0.01$), a moderate but somewhat weaker correlation than that observed for the Japanese music majors.

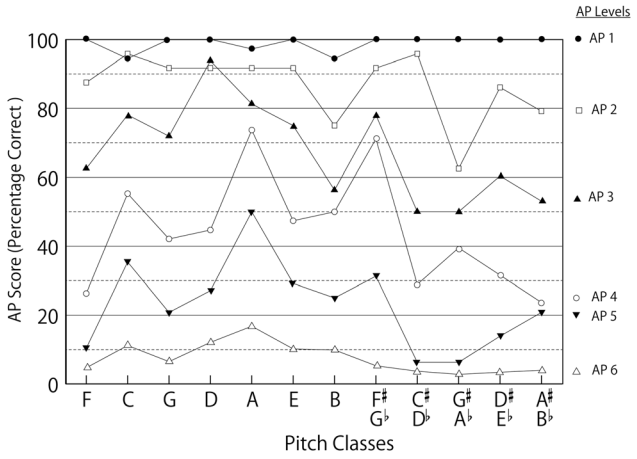

FIG. 5. Averaged AP scores of the Polish participants in groups of different AP levels as a function of pitch classes arranged in the order of tones on the circle of fifths.

The rightmost column of Table IV displays the proportion of the participants whose primary or secondary instrument was the piano. Unlike what was observed in the Japanese music majors and trained non-music majors, there appears to be no clear relationship in the Polish music students between the AP accuracy and the proportion of participants trained in the piano. A χ^2 analysis showed that the proportion of participants trained in the piano was not homogeneous among six AP groups of different accuracy levels [χ^2 (5) = 11.71, $p < 0.05$]; the proportion was significantly larger than the expected value for only AP 4 ($p < 0.05$). As a whole, the proportion of participants trained in the piano was lower for the Polish music students than for the Japanese music majors (0.724 vs 0.939). However, this difference is not very informative because the Polish participants whose primary or secondary instrument was the piano may not be comparable to the Japanese participants who had received lessons on a keyboard instrument for 6 years and more.

The proportion of AP participants and AP scores are presented as a function of the age of music training onset in Table V. The earlier the music training onset, the higher the proportion of AP. This trend was similar to that observed with the Japanese music majors, but the proportion of AP in the Polish music students who had received early music training was substantially lower than that observed in the corresponding Japanese music majors. The average AP score decreased with the increasing age of music training onset. A one-way ANOVA on the AP score revealed a significant effect of the age of music training onset [$F(4, 245) = 11.13$,

TABLE IV. Group summary of Polish music students.

			White-key notes	Black-key notes		
Group	Range of AP scores	*n* (cumulative proportion)	Average score (SD)	Average score (SD)	Age of music training onset (SD)	Piano
AP 1	95–100	18 (0.072)	98.0 (3.3)	100.0 (0)	6.25 (0.94)	0.833
AP 2	80–95	12 (0.120)	89.3 (6.5)	83.3 (10.1)	5.92 (1.17)	0.917
AP 3	60–80	16 (0.184)	74.1 (8.2)	58.5 (10.5)	6.31 (1.74)	0.563
AP 4	40–60	19 (0.260)	48.5 (12.2)	38.3 (10.7)	7.74 (1.76)	0.947
AP 5	20–40	24 (0.356)	28.3 (6.1)	15.5 (8.3)	7.42 (1.41)	0.625
AP 6	0–20	161 (1.000)	10.2 (7.9)	3.5 (5.8)	8.39 (2.97)	0.702
Total		250			7.84 (2.67)	0.724

TABLE V. Age of music training onset and proportion of AP participants for Polish participants.

Age of music training onset	n	n (proportion of participants) AP 1	AP 1 and 2	AP 1, 2, and 3	Average AP score (SD)
4 or earlier	8	2 (0.250)	4 (0.500)	6 (0.760)	67.5 (37.5)
5	8	1 (0.125)	3 (0.375)	4 (0.500)	46.5 (42.4)
6	39	6 (0.154)	9 (0.231)	14 (0.359)	39.4 (36.7)
7	119	9 (0.076)	14 (0.118)	20 (0.168)	25.0 (30.4)
8 or later	76	0 (0.000)	0 (0.000)	2 (0.026)	13.4 (15.1)
Total	250	18 (0.072)	30 (0.120)	46 (0.184)	25.8 (30.8)

$MS_e = 0.08$, $p < 0.001$, $\eta_p^2 = 0.154$]. Multiple comparisons (Tukey's HSD) revealed a significant difference between the 8-year-or-later group and all other groups, and between the 7-year group and the 4-year-or-earlier group ($p < 0.05$). These results from the Polish music students again support the view that AP is effectively acquired through early music training (6 years or earlier), although less pronounced than in the Japanese music majors.

The overall average of AP scores was substantially lower in the Polish music students than in the Japanese music majors (25.8 vs 67.3). This marked difference may originate partly from the fact that the Polish music students began their music training at ages later than the Japanese students. We conducted a two-way ANOVA with ethnicity and the age of training onset as between-subject factors (the Polish 7-year and 8-year-or-later groups, and the Japanese 3-years-or-earlier and 4-year groups were each combined). The results revealed a significant effect of ethnicity [$F(1, 356) = 9.05$, $MS_e = 0.065$, $p < 0.005$, $\eta_p^2 = 0.025$], and no significant interaction between ethnicity and the age of training onset [$F(3, 356) = 0.78$, $p = 0.51$, $\eta_p^2 = 0.007$]. We further analyzed the AP scores between the Polish music students and the Japanese music majors by an analysis of covariance (ANCOVA) with the age of music training onset as a covariate. The effect of ethnicity was again significant when the effect of the age of training onset was partialled out [$F(1, 361) = 67.26$, $MS_e = 0.085$, $p < 0.001$, $\eta_p^2 = 0.157$]. These results suggest that AP is associated also with other factors than the age of music training onset, for example, training on the keyboard instrument, the nature of music training, and some other factors perhaps including genetic predispositions.

IV. GENERAL DISCUSSION

In the two studies conducted in Japan and Poland, a large number of students with varying amounts of musical training were tested on the absolute pitch-naming task. The results provided reliable and detailed estimates of the distribution of AP ability among music students and revealed a pronounced difference in the prevalence of AP between the Japanese and the Polish music students. The percentage of AP (80% correct or higher) among the Japanese music students was nearly 50%, approximately four times larger than among the Polish students. The proportion of AP observed is heavily dependent on the amount and nature of musical training participants received, potential selection biases, the criterion of AP, and details of testing conditions. Our AP test was independently designed and conducted at the outset in Japan and Poland, and consequently, there are several differences in procedures for AP testing: The number of test items (approximately two times as many for the Japanese sample), time intervals for responding (two times as long for the Polish sample), and the form of questionnaires about music background. These differences may have produced a certain amount of disparity in the data obtained from Japanese and Polish participants. In other respects, however, the two studies were nearly equivalent and students attending entire classes or randomly sampled participants were tested to minimize selection biases, ensuring a reasonable comparison between the two populations.

One possible disparity in our data is the difference in the reported levels of musical training between the Japanese and the Polish participants. The Polish participants were all enrolled at the Fryderyk Chopin University of Music in Warsaw, one of the world's leading conservatory-level institutions primarily focused on training professional musicians. In contrast, the Japanese music students were those who majored in music in a curriculum principally focused upon training music teachers in the Faculty of Education at Niigata University. It is reasonable to assume that the Polish students underwent a higher level of music training, achieved a more advanced level of musical achievement, and passed through more rigorous selection processes than the Japanese music majors. In case the level of professional musical training was associated with AP, the Polish music students would be expected to achieve a higher performance in pitch naming than the Japanese music students. However, in fact, the observed difference in the pitch-naming performance was opposite in direction to that expected from the existing difference in professional musical training. From these unexpected results, the higher prevalence of AP observed in the Japanese music majors than in the Polish music students would be even more impressive.

Several large-scale investigations have reported a range of estimates on the AP prevalence among musicians and non-musicians. However, some of them are based on a questionnaire survey or a web-based test that has the inevitable drawback that self-selection biases cannot be ruled out (for example, Athos *et al.*, 2007; Baharloo *et al.*, 1998; Gregersen *et al.*, 2000; Sergeant, 1969). Many others conducted a direct AP test on participants individually or in a group (for example, Bermudez and Zatorre, 2009; Lee *et al.*, 2011; Wilson *et al.*, 2012), but most of them did not report the details of the method of sampling participants and probably included an unknown degree of selection biases. Among these previous investigations is the one by Deutsch *et al.* (2006) whose results are comparable to ours. Deutsch *et al.* (2006) conducted an on-site AP test on students enrolled at the Central Conservatory of Music in Beijing (China) and students enrolled at Eastman School of Music in Rochester (United States) and presented the percentage of participants who met an AP criterion (85% correct or higher) for subgroups divided according to the age of music training onset. The recalculated percentage of AP participants among subgroups who had begun their music training between 4 and 9

years was 55.8% (43/77) for the Chinese students and 4.8% (5/105) for the U.S. students. For comparison, we recalculated the percentage of our participants who met the same criterion; it was 43.6% (51/117) for the Japanese music majors, 6.5% (76/1163) for the Japanese non-music majors, and 10.0% (25/250) for the Polish music students. The percentage of AP among the Japanese music majors was roughly comparable to that among the Chinese students; both were substantially high, although the Chinese percentage was somewhat higher. In contrast, the proportions of AP for the U.S. music majors, the Polish music majors, and the Japanese non-music majors were equivalently lower. This contrast in the AP prevalence supports the claim that AP is more common among East Asian musicians than among non-Asian musicians (Gregersen *et al.*, 1999, 2000; Deutsch *et al.*, 2006; Deutsch *et al.*, 2009; Schellenberg and Trehub, 2008).

Researchers have often considered ethnic differences in AP as an indication that there exist genetic predispositions toward AP (Gregersen *et al.*, 1999). Baharloo *et al.* (1998) conducted a large-scale survey on AP and concluded that a familial aggregation of AP demonstrates that there are genetic mechanisms involved in the development of AP. However, it is inherently difficult to assess the genetic contributions to almost all human traits, because genetic factors and environmental factors are inseparably connected and the high prevalence and familial aggregation of AP are not reliable evidence for the contribution of the genetic factors (Levitin and Zatorre, 2003). We should refrain from making further mention of the genetic contribution to AP, until an AP gene is located.

Deutsch *et al.* (2006) associated the high prevalence of AP among Chinese music students with exposure to a tone language during a sensitive period of language acquisition. In their experiment, all Chinese participants spoke Mandarin Chinese, a tone language, as their native language, whereas all the U.S. students were non-tone-language speakers. According to their argument, the Chinese students speaking Mandarin might have been particularly sensitive to the absolute value of the pitch of speech sounds to which they were exposed in infancy, and later might have been better prepared to learn musical absolute pitch than non-tone-language speakers. This view opens up an inspiring perspective on AP, suggesting a close association between music and language processing.

However, the tone-language account is at least partially inconsistent with our results that AP is substantially more prevalent among the Japanese music majors, although Japanese is not a tone language but a pitch-accent language. Deutsch (Deutsch, 2006; Henthorn and Deutsch, 2007) extended the tone-language explanation so that the same principle that applied to tone languages could apply to speakers of pitch-accent languages such as Japanese and certain Korean dialects. They conjectured that a higher prevalence of absolute pitch might also exist among people who were exposed to a pitch-accent language in infancy. However, Japanese pitch accent is relatively simple compared to Chinese lexical tone and plays only a small part in language communication (Vance, 1987). Japanese occupies an intermediate position on the continuum of tonal density between English, a typical stress language, and Mandarin, a typical tone language (Hyman, 2009). Moreover, in Japanese, there are only two pitch levels (high and low) with less elaborate mappings between meaning and pitch and a portion of two-syllable homonymous Japanese words have different meanings depending on their pitch pattern (low-high or high-low) (Hirayama, 1957; Kindaichi and Akinaga, 2010). Therefore, exposure to pitch-accent language may play a limited role if any in creating a predisposition to acquire AP.

Our results are not particularly relevant for evaluating the genetic view and the tone-language explanation of AP, but we could state more clearly the relevance of musical experience to the AP prevalence. As repeatedly demonstrated to date (Baharloo *et al.*, 1998; Deutsch *et al.*, 2006; Wilson *et al.*, 2012), the age of music training onset correlated significantly to AP performance in both the Japanese and Polish music students. It is commonly accepted that there is a sensitive period for AP learning that spans the age from 3 to 7 years, and music training during this period is most efficient for AP acquisition (Miyazaki and Ogawa, 2006; Takeuchi and Hulse, 1993; Ward, 1999). In line with this view, our participants in both Japan and Poland who began music training earlier achieved a higher level of performance in the AP test. The percentage of participants who began their music training at 6 years or earlier was approximately 90% for the Japanese students, but only 32% for the Polish students. On average, the Japanese students had a music training onset more than 2 years earlier than the Polish students. The earlier music training the Japanese music majors received during the sensitive period for AP may contribute to the higher AP prevalence among them.

The age of beginning music training is of course not the only environmental factor contributing to AP; there were a considerable number of participants who had early music training but had no AP, and others, although small in number, who began music training at 7 years or later had high AP. Therefore, it is highly likely that the interaction among multiple environmental factors contributes to the AP development. One related factor probably interacting with the age of initial music training is enrollment in music school for children providing piano lessons. There was a significant correlation between the proportion of the Japanese musically trained participants who had attended the Yamaha Music School and AP accuracy. Yamaha Music Schools offer lessons in the piano or electric organ to preschool children, beginning usually at the age of 3–5 years, and in parallel provide training based on the fixed-do solfège singing that is assumed to facilitate the AP development (Miyazaki and Ogawa, 2006). Related to this factor, the proportion of participants who had been trained in keyboard instruments, typically the piano, was significantly higher for the Japanese musically trained participants than for the Polish students. Piano is a particularly effective instrument for learning AP, because it has a consistent pitch-key (pitch-label) mapping and supports fixed-do solfège instruction. Such music training, especially for preschool children, emphasizing fixed-do solfège coupled with piano lessons is common in Japan, but not in Poland.

In conclusion, our data suggest that the three related environmental conditions considered previously (the age of

initial music training, exposure to the fixed-do instruction, and training in piano) interact with each other and probably with genetic predispositions to facilitate the AP development. This is principally in line with the recent finding of Wilson *et al*. (2012) that a combination of factors including early exposure to fixed-do training, training onset in the sensitive period, and a family history of AP is most relevant in AP musicians. Exposure to tone language or pitch-accent language may also be associated with AP in particular populations. It is most likely that AP is not a simple phenomenon produced by a single factor but a complex set of phenomena with varying type and degree of accuracy to which all these factors, including environmental and genetic, contribute in a complicated interacting manner.

ACKNOWLEDGMENTS

This research was supported by Grant-in-Aid for Scientific Research (C) (No. 21500256) from the Japan Society for the Promotion of Science to K.M. and by Research Grant No. N105 028 31/3210 from the Ministry of Science and Higher Education (Poland) to A.R.

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This article appeared in Journal of the Acoustical Society of America, 132 (5), 3484-3493 (2012), and may be found at http://link.aip.org/link/?JAS/132/3484*.*