Absolute pitch among students at the Shanghai Conservatory of Music: A large-scale direct-test study

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This paper reports a large-scale direct-test study of absolute pitch (AP) in students at the Shanghai Conservatory of Music. Overall note-naming scores were very high, with high scores correlating positively with early onset of musical training. Students who had begun training at age ≤5 yr scored 83% correct not allowing for semitone errors and 90% correct allowing for semitone errors. Performance levels were higher for white key pitches than for black key pitches. This effect was greater for orchestral performers than for pianists, indicating that it cannot be attributed to early training on the piano. Rather, accuracy in identifying notes of different names (C, C#, D, etc.) correlated with their frequency of occurrence in a large sample of music taken from the Western tonal repertoire. There was also an effect of pitch range, so that performance on tones in the two-octave range beginning on Middle C was higher than on tones in the octave below Middle C. In addition, semitone errors tended to be on the sharp side. The evidence also ran counter to the hypothesis, previously advanced by others, that the note A plays a special role in pitch identification judgments.
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I. INTRODUCTION

Absolute pitch (AP), otherwise known as perfect pitch, is the ability to name or produce a note of given pitch in the absence of a reference note. It is extremely rare in the U.S. and Europe, with a prevalence often estimated as less than one in 10 000 (cf. Bachem, 1955). Given its rarity, studies of this ability have tended to rely on small numbers of subjects, informal reports, questionnaires, and Web-based testing, so it has been difficult to document its genesis and characteristics with confidence (Deutsch, 2013). However, large-scale direct-test studies have recently found that the prevalence of AP was high among music students who were speakers of tone languages, including those who were students at a Chinese music conservatory (Deutsch *et al.*, 2006), musically trained university students in Taiwan (Lee and Lee, 2010) and South China (Peng *et al.*, 2013) and among fluent tone language speakers at an American music conservatory (Deutsch *et al.*, 2009) and musicians in Melbourne, Australia (Wilson *et al.*, 2012). The study reported here capitalized on the high prevalence of AP among tone language speakers to examine its characteristics in a fine-grained fashion by studying a large group of subjects in a Chinese music conservatory without self-selection from the target population. The study was conducted at the Shanghai Conservatory of Music because this is a world-renowned music conservatory with an excellent curriculum in the area of Western tonal music. The issues examined were the effects of subject characteristics, naming accuracy as a function of pitch class and octave placement and, when naming errors occurred, the relationship between the named and actual note.

Previous studies, both involving large-scale direct tests (Deutsch *et al.*, 2006; Deutsch *et al.*, 2009; Lee and Lee, 2010; Miyazaki *et al.*, 2012; Wilson *et al.*, 2012; Peng *et al.*, 2013) and also employing smaller numbers of subjects or Web or survey procedures (Bachem, 1948; Sergeant, 1969; Miyazaki, 1988; Profita and Bidder, 1988; Baharloo *et al.*, 1998; Baharloo *et al.*, 2000; Gregersen *et al.*, 1999, 2001; Vanzella and Schellenberg, 2010; Dooley and Deutsch, 2010, 2011), have found a strong association between the prevalence of AP and early onset of musical training; this association was also examined here.

In addition, it has been found that AP possessors varied in the speed and accuracy with which they named different pitch classes. In general, pitches corresponding to white keys on the keyboard (C, D, E, F, G, A, B) have been identified with greater accuracy and speed than those corresponding to black keys (C#/Db, D#/Eb, F#/Gb, G#/Ab, A#/Bb) (Sergeant, 1969; Carroll, 1975; Miyazaki, 1988, 1989, 1990; Takeuchi and Hulse, 1991, 1993; Simpson and Huron, 1994; Marvin and Brinkman, 2000; Vanzella and Schellenberg, 2010; Athos *et al.*, 2007; Bermudez and Zatorre, 2009; Miyazaki *et al.*, 2012). Two main explanations for this effect have been advanced. Miyazaki (1989, 1990) proposed that most AP possessors begin musical training on the piano early in life and that such training starts with simple five-finger exercises using only white keys with black keys being

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introduced as training proceeds. He argued, therefore, that the white key advantage in AP judgments is due to piano practice in early childhood. An alternative explanation was advanced by Takeuchi and Hulse (1991, 1993), who pointed out, based on general observation, that white-key pitches occur more frequently than black-key pitches in Western tonal music, and so should be better processed (see also Simpson and Huron, 1994; Marvin and Brinkmann, 2000; Vanzella and Schellenberg, 2010). These two hypotheses were here examined, taking all pitch classes into consideration.

Another issue that was explored concerns the octave placement ("register") of the note to be named. It has been observed in several studies involving small numbers of subjects that AP possessors named notes more accurately when they were in central pitch registers (Bachem, 1948; Rakowski, 1978; Rakowski and Morawska-Bungeler, 1987; Miyazaki, 1989). In the present study, naming accuracy was compared for notes in three central registers: The octave beginning on Middle C, the octave just below this, and the octave just above this.

A further issue concerns the suggested tendency to misidentify notes in the sharp direction. In a Web-based study, Athos *et al.* (2007) found that semitone errors occurred in both the sharp and flat directions, with deviations tending more in the sharp direction, and increasing with advancing age (see also Ward, 1999). The present study examined this issue of direction of error, considering both semitone errors and also errors larger than a semitone. As a related issue, based on their finding that the note G# was frequently misidentified as A, Athos *et al.* (2007) suggested that because Concert A is employed as a reference for orchestra tuning, pitch class A might serve as a "perceptual magnet" (Kuhl, 1991) so as to enlarge the perceptual region assumed by listeners to correspond to this note. This hypothesis was also examined in the present study.

II. METHOD

A. Procedure

The subjects were administered a test for AP that was the same as that given in Deutsch *et al.* (Deutsch *et al.*, 2006; Deutsch *et al.*, 2009), Dooley and Deutsch (2010, 2011), and Peng *et al.* (2013). They were presented successively with the 36 notes that spanned the three-octave range from C_3 (131 Hz) to B_5 (988 Hz) and wrote down the name of each note (C, C#, D, etc.) when they heard it. To minimize the involvement of relative pitch in the judgments, all successively presented notes were separated by an interval that was larger than an octave. The notes were piano tones that were generated on a Kurzweil K2000 synthesizer tuned to $A_4 = 440$ Hz. They were presented in three blocks of 12 notes each, with intervals of 4.25 s between onsets of the notes within a block, and 39 s pauses between blocks. A practice block consisting of four successive notes preceded the three test blocks. No feedback was provided, either for the practice block or for the test blocks. The notes were presented to subjects via a compact disk player, amplifier, and two loudspeakers.

B. Subjects

The subjects were 160 first or second year students (48 male, 112 female; average age 18.98 yr; age range: 18–23 yr) at the Shanghai Conservatory of Music. Their studies all focused on Western tonal music, and they had all begun musical training on a Western instrument. The subjects were tested in class where they were taking a required course for those with a focus on Western tonal music. All the students in the class were invited to take the test, and all agreed to do so. The obtained data were therefore representative of those students at the conservatory with a focus on Western tonal music. All the subjects were native speakers of a tone language, and they all spoke Mandarin.

III. RESULTS

A. Performance as a function of subject characteristics

The effect of age of onset of musical training, and of gender, were evaluated. To examine the effect of age of onset of training, the subject population was divided into three groups: Those who had begun musical training at age ≤ 5 ($n = 78$; 18 male, 60 female), at age 6–9 ($n = 57$; 14 male, 43 female), and at age ≥ 10 ($n = 25$; 16 male, 9 female). The average percentage correct for subjects in each of these age groups was then calculated, both allowing and not allowing for semitone errors. The results are shown in Fig. 1. It can be seen that the overall performance level was very high, and that in addition there was a large effect of age of onset of musical training. Where semitone errors were not allowed, the effect of age of onset was highly significant [$F(2,157) = 47.84$, $p < 0.001$]. *Post hoc* comparisons with Bonferroni correction found that the difference between age-of-onset groups ≤ 5 and 6–9 was highly significant ($p < 0.01$) as it was between groups 6–9 and ≥ 10 ($p < 0.001$) and between groups ≤ 5 and ≥ 10 ($p < 0.001$). Where semitone errors were allowed, the overall effect of age of onset

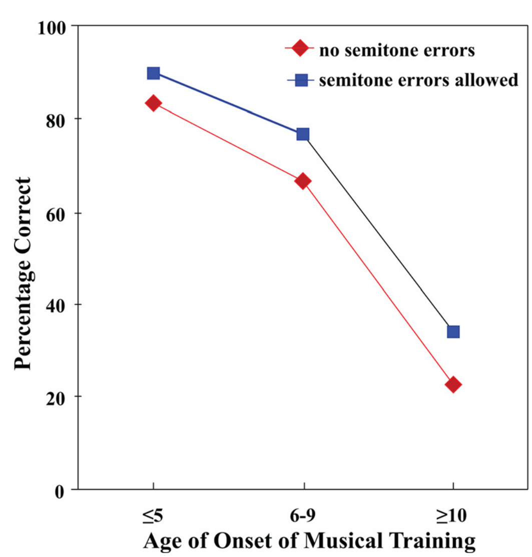

FIG. 1. (Color online) Average percentage correct on the test of absolute pitch as a function of age of onset of musical training. Age of onset of training ≤ 5 yr: $n = 78$; 6–9 yr: $n = 57$; ≥ 10 yr: $n = 25$.

was also highly significant [$F(2,157) = 61.77$, $p < 0.001$). *Post hoc* comparisons with Bonferroni correction found that the difference between age-of-onset groups ≤5 and 6–9 was highly significant ($p < 0.01$), as it was between groups 6–9 and ≥10 ($p < 0.001$), and between groups ≤5 and ≥10 ($p < 0.001$).

The effect of gender was evaluated for each age-of-onset group separately, and in all cases was nonsignificant. Specifically, where semitone errors were not allowed, the effect was nonsignificant for age-of-onset group ≤5 [$t(76) = 0.42$, $p > 0.1$], as it was for group 6–9 [$t(55) = 0.87$, $p > 0.1$], and group ≥10 [$t(23) = 0.63$, $p > 0.1$]. Where semitone errors were allowed, the effect of gender for group ≤5 was also nonsignificant [$t(76) = 0.96$, $p > 0.1$], as it was for group 6–9 [$t(55) = 0.26$, $p > 0.1$], and group ≥10 [$t(23) = 0.83$, $p > 0.1$].

Given the low performance level for age-of-onset group ≥10, the remaining analyses were carried out taking only those subjects ($n = 135$) who had begun musical training at age ≤9.

B. Performance as a function of stimulus characteristics

1. Effects of pitch class

As described earlier, it has been found in several studies that white key pitches were better identified than black key pitches, and two major hypotheses have been advanced to explain this phenomenon. The first hypothesis proposes that the effect is due to early training on the piano, and the second that it is due to the higher prevalence of white key pitches in Western tonal music. To examine this issue, several types of analysis were carried out. First, to replicate the basic effect, performance levels on black and white key pitches were compared, taking all subjects who had begun training at age ≤9. The results are shown in Fig. 2, and it can be seen that a clear black/white key effect was obtained. (The false alarm rates were exceedingly low, with false alarms for white key pitches exceeding those for black key pitches by only 0.49%.) A repeated measures analysis of variance (ANOVA) was carried out, with age-of-onset (≤5 vs 6–9) as a between-subjects factor, and key pitch (black vs white) as a within-subjects factor. The effect of age-of-onset was highly significant [$F(1,133) = 12.6$, $p = 0.001$] as was the effect of black vs white key pitch [$F(1,133) = 55.78$, $p < 0.001$]; the interaction between these factors was nonsignificant [$F(1,133) = 2.84$, $p > 0.05$]. The basic black/white key effect was therefore replicated.

To test whether the black/white key effect can be attributed to early training on the piano, two specialized groups of instrumentalist were then compared. The first consisted of piano majors who had begun musical training on the piano, and also currently had piano as their primary instrument. The second consisted of orchestral music majors who had begun musical training on a non-keyboard instrument, and whose current primary instrument was in the same family; these constituted 20 string players, two flautists, one horn player, and one trumpet player.

The effect of instrumentalist type was evaluated separately for those with age-of-onset ≤5 and 6–9, and the results are shown in Fig. 3. For age of onset ≤5, the groups consisted of 20 pianists and 11 orchestral performers. The black/white key effect was highly significant [$F(1,29) = 17.80$, $p < 0.001$], with overall superior performance on the white key pitches. (The false alarm rates were again exceedingly low with those for white key pitches exceeding those for black key pitches by only 0.45%.) The overall effect of instrumentalist type was significant [$F(1,29) = 5.25$, $p < 0.05$], with the percentage of correct response being higher for the pianists than for the orchestral performers. Importantly, and contrary to expectation based on the hypothesis that early piano training is responsible for the effect, the interaction between these two factors was significant [$F(1,29) = 4.69$, $p < 0.05$], in that the orchestral performers displayed a larger black/white key effect than did the pianists. For age of onset 6–9, the groups consisted of 12 pianists and 13 orchestral performers. For these subjects, the black/white key effect was highly significant [$F(1,23) = 12.56$, $p < 0.01$]; however, the effect of instrumentalist type was nonsignificant [$F(1,23) = 0.02$, $p > 0.1$], as was the interaction between these two factors [$F(1,23) = 0.46$,

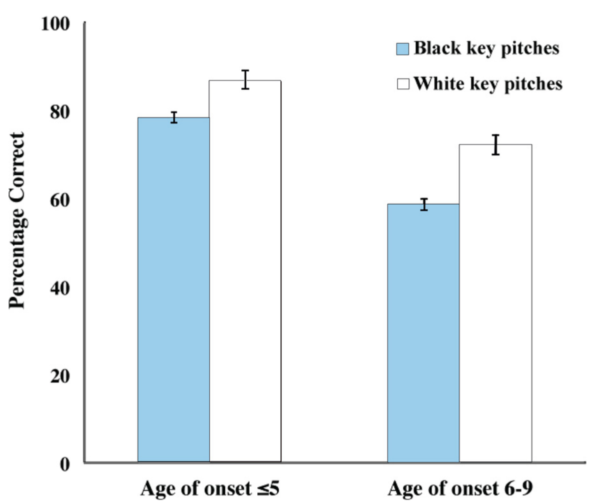

FIG. 2. (Color online) Percent correct identification for black key pitches, and white key pitches, displayed separately for subjects with age-of-onset of musical training ≤5 and 6–9 yr.

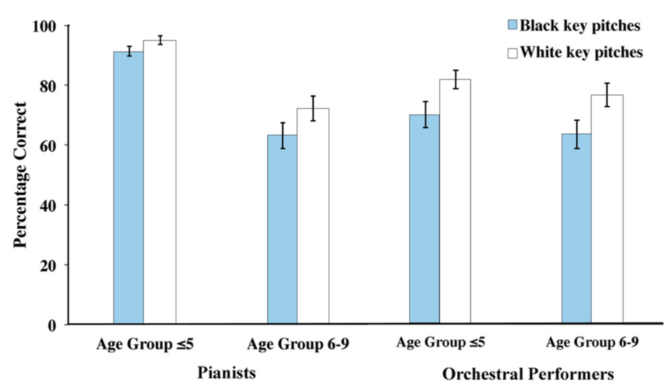

FIG. 3. (Color online) Percent correct identification of black key pitches and white key pitches for subjects with age-of-onset of musical training ≤5 and 6–9 yr. The data are shown for two specialist groups separately. Pianists: Piano majors who had begun musical training on the piano and currently had piano as their primary instrument. Orchestral performers: Orchestral music majors who had begun musical training on a non-keyboard instrument and whose current primary instrument was in the same instrument family.

$p > 0.1$]. We can conclude from these analyses that the black/white key effect cannot be explained by early training on the piano.

The alternative hypothesis was then tested that the black/white key effect results from the higher frequency of occurrence of white-key pitches in Western tonal music. The percentage correct identification was calculated for each pitch class separately, taking all subjects who had begun training at age ≤ 9. These percentages were then correlated with the number of occurrences of each pitch class in Barlow and Morgenstern's Electronic Dictionary of Musical Themes (2008). The resultant plot is shown in Fig. 4. There was a significant correlation between note-naming accuracy and frequency of occurrence of the different pitch classes in this representative note collection ($R^2 = 0.6489$; $p < 0.01$). This finding is particularly striking considering that the repertoire for courses at the Shanghai Conservatory taken by students with a focus on Western tonal music, although having its primary input from Western tonal music, also has more input from Russian and Chinese music than occurs in Western music conservatories. The finding therefore provides further evidence that the black/white key effect results from differences in frequency of exposure to the different pitch classes.

2. Effects of octave placement

As described earlier, it has been found in studies employing small numbers of subjects that AP possessors name notes most accurately when these are in central pitch registers. To examine the effect of register in all those who had begun musical training at age ≤ 9, we computed the average performance level at each of the three octaves employed: C_3 - B_3 (F0 = 131 – 245 Hz); C_4 - B_4 (F0 = 262 – 494 Hz), and C_5 - B_5 (F0 = 523 – 988 Hz). The results, both allowing and not allowing for semitone errors, are shown on Fig. 5. Not allowing for semitone errors, performance levels were roughly equivalent for notes in the middle and higher octaves, and the performance level was lower for notes in the lower octave. A repeated measures ANOVA was carried out, with age of onset (≤ 5 vs 6–9) as a between-subjects factor, and octave range (lower, middle, higher) as a within-subjects factor. The effect of age of onset was highly significant [$F(1,133) = 12.29$, $p = 0.001$], the effect of octave range was also highly significant [$F(2,266) = 25.40$, $p < 0.001$]; however, the interaction between age of onset and octave range was nonsignificant [$F(2,266) = 1.44$, $p > 0.1$]. On *post hoc* comparisons with Bonferroni correction, the difference between the lower and middle octave was highly significant ($p < 0.001$), and the difference between the lower and higher octave was highly significant ($p < 0.001$); however, the difference between the middle and higher octave was nonsignificant ($p > 0.1$). Allowing for semitone errors, the effect of age of onset was highly significant [$F(1,133) = 12.13$, $p = 0.001$], and the effect of octave range was also highly significant [$F(2,266) = 17.67$, $p < 0.001$]; however, the interaction between age of onset and octave range was nonsignificant [$F(2,266) = 1.34$, $p > 0.1$]. On *post hoc* comparisons with Bonferroni correction, the difference between the lower and middle octave was highly significant ($p < 0.001$), and the difference between the lower and higher octave was highly significant ($p < 0.001$); however, the difference between the middle and higher octave was nonsignificant ($p > 0.1$). These effects of octave range were similar to those found in previous studies employing smaller numbers of subjects. We may conjecture that, analogous to the effect of pitch class, they arose from differences in frequency of exposure to notes in different pitch ranges. One way to explore this conjecture would be to determine the frequency of occurrence of notes in the different octaves in a large sample taken from the repertoire of Western tonal music.

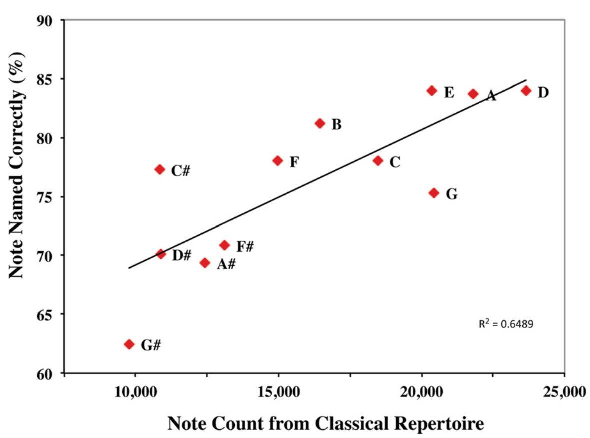

FIG. 4. (Color online) Average percentage correct on the test of absolute pitch for each pitch class, plotted against the number of occurrences of each pitch class in a large sample of music taken from the classical repertoire. Because the counts are of pitch class, enharmonically equivalent notes (for example, F# and Gb) are treated as equivalent. Data are for all subjects with age-of-onset of musical training ≤ 9 yr.

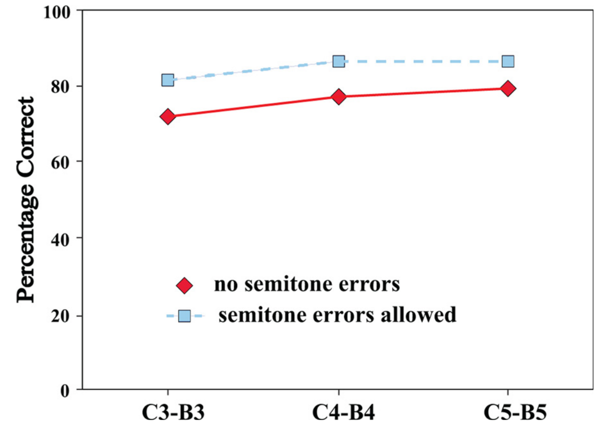

FIG. 5. (Color online) Average percentage correct on the test of absolute pitch as a function of octave range: C3 - B3 (F0 = 131 – 245 Hz); C4 - B4 (F0 = 262 – 494 Hz), and C5 - B5 (F0 = 523 – 988 Hz). Data are for all subjects with age-of-onset of musical training ≤ 9 yr.

C. Characteristics of note naming errors

We next consider the characteristics of note naming when incorrect naming occurred, by considering relationships between the named and actual notes. First we plotted, for all subjects who had begun training at age ≤ 9, the relationships between the named and actual notes, taking black and white key pitches separately. As shown in Fig. 6, for the large majority of responses, the named and actual notes were identical. This is as expected from the data shown on Fig. 1, which displays a very high performance level on the part of the subjects. The next most probable category of response was a semitone removed from the actual note -generally termed a semitone error. The next most probable category of response was two semitones removed from the actual note, and responses that were 3, 4, and 5 semitones removed from the actual note were very rare.

To determine whether there was a significant effect of distance between the named and actual note, a two-way ANOVA was performed, averaging over responses in the sharp and flat direction, with black vs white key pitch for the actual note, and distance between the named and actual note (discounting zero distance) as factors. The effect of black vs white key pitch for the actual note was highly significant [$F(1,134) = 52.83$, $p < 0.001$], as was the effect of distance between the named and actual note [$F(5,134) = 43.95$, $p < 0.001$]. The interaction between these two factors was also highly significant [$F(5,670) = 10.81$, $p < 0.001$] and indicated a higher tendency for black key pitches to be misnamed as white key pitches than for white key pitches to be misnamed as black key pitches.

Post hoc comparisons with Bonferroni correction for black and white key pitches combined showed that the effect of distance between the named and actual note was highly significant for distances of 1 vs 2 semitones ($p < 0.001$) and 2 vs 3 semitones ($p < 0.001$). However, the effect was nonsignificant for 3 vs 4 semitones ($p > 0.1$), 4 vs 5 semitones ($p > 0.1$), and 5 vs 6 semitones ($p > 0.1$). Further *post hoc* comparisons with Bonferroni correction showed that for white key actual pitches taken alone, the effect of distance between the named and actual note was significant for 1 vs 2 semitones ($p = 0.05$), and highly significant for 2 vs 3 semitones ($p < 0.001$). However, the effect was nonsignificant for 3 vs 4 semitones ($p > 0.1$), 4 vs 5 semitones ($p > 0.05$), and 5 vs 6 semitones ($p > 0.1$). For black key actual pitches taken alone, the effect of distance between the named and actual note was highly significant for 1 vs 2 semitones ($p < 0.001$), and 2 vs 3 semitones ($p = 0.01$). However, the effect was nonsignificant for 3 vs 4 semitones ($p > 0.1$), 4 vs 5 semitones ($p > 0.1$), and 5 vs 6 semitones ($p > 0.1$). The overall finding here that when naming errors occurred, the named note tended to be close to the actual note, is as intuitively expected, but had not so far been established formally.

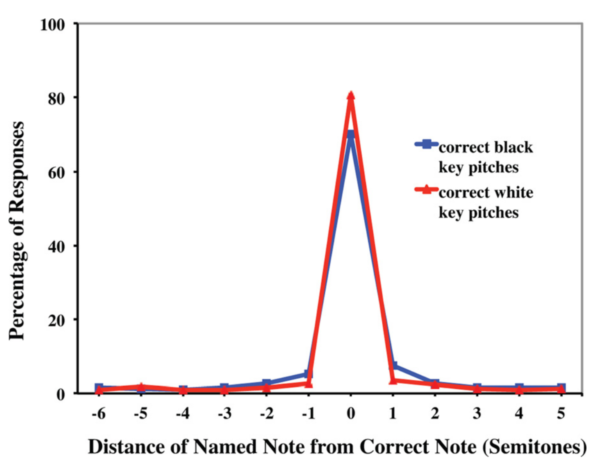

FIG. 6. (Color online) Percentage of responses as a function of distance between the named note and the actual note. Data are for all subjects with age-of-onset of musical training ≤9 yr.

We next inquire whether there was a tendency for identification errors to be in the sharp or flat direction. To determine whether there was a significant difference in the percentage of responses as a function of direction of error (sharp vs flat), a two-way ANOVA was performed, considering only semitone errors, with black vs white key pitch and direction of error (sharp vs flat) as factors. As expected, the black vs white key comparison was highly significant [$F(1,134) = 31.59$, $p < 0.001$] with more errors on black key pitches. The sharp vs flat comparison was also highly significant [$F(1,134) = 6.97$, $p < 0.01$] with more errors in the sharp direction. *Post hoc* comparisons showed that for black key pitches, the difference between errors in the sharp vs flat direction was significant ($p < 0.05$). For white key pitches, this difference instead appeared as a nonsignificant trend ($p = 0.09$); the lack of significance here can be attributed to the very small number of errors that were made on white key pitches.

We next inquire whether the sharp/flat effect was confined to semitone errors, or whether it extended to larger distances between the named and actual notes. To explore this issue, a two-way ANOVA was performed, with errors summed over distances of 2, 3, 4, and 5 semitones, again with black vs white key pitch and direction of error (sharp vs flat) as factors. Again as expected, the black vs white key comparison was highly significant [$F(1,134) = 7.99$, $p < 0.01$] with more errors on black key pitches. However, the sharp vs flat comparison was nonsignificant [$F(1,134) = 1.25$, $p > 0.1$]. It appears, therefore, that the sharp/flat effect is confined to semitone errors.

We next explore the hypothesis that pitch class A acts as a "perceptual magnet" for note naming (Athos *et al.*, 2007). If this hypothesis were correct, then the note G# should be misidentified more often as A than as G, and the note A# should be misidentified more often as A than as B. It was here found that when the correct note was G#, the probability of its being misidentified as A was 7.9%, whereas the probability of its being misidentified as G was 6.17%. The direction of this difference was as expected from the perceptual magnet hypothesis, although the difference was nonsignificant [$t(134) = 0.89$, $p > 0.1$]. However, when the correct note was A#, the probability of its being misidentified as A was 3.21%, whereas the probability of its being misidentified as B was far larger, at 12.59%. The tendency to misname A# as B rather than as A was highly significant [$t(134) = 4.25$, $p < 0.001$], and ran counter to the perceptual magnet hypothesis. This pattern of results can therefore be attributed instead to a general tendency to misidentify notes as a semitone sharp.

IV. DISCUSSION

The very high overall level of performance on the AP test found in this study is consistent with findings from previous large scale direct-test studies of tone language speakers at the Central Conservatory of Music in Beijing, China (Deutsch *et al.*, 2006), musically trained students at National Taiwan Normal University (Lee and Lee, 2010), and at music departments in four universities in South China (Peng *et al.*, 2013), as well as from tone language speakers participating in large scale studies that included mainly non-tone language speakers, at USC Thornton School of Music in the U.S. (Deutsch *et al.*, 2009), and musicians in Melbourne, Australia (Wilson *et al.*, 2012). This contrasts with the low prevalence of AP in large-scale studies of non-tone language speakers at Eastman School of Music (Deutsch *et al.*, 2006) and the USC Thornton School of Music (Deutsch *et al.* 2009) in the U.S., and at the Fryderyk Chopin University of Music in Poland (Miyazaki *et al.*, 2012). The prevalence of AP among music majors at Niigata University in Japan, where pitch accent language is spoken, has been found to be higher than among nontone language speakers, although somewhat lower than among speakers of tone language (Miyazaki *et al.*, 2012).

The present study also replicated the strong association between the prevalence of AP and early age of onset of musical training that had previously been obtained in large-scale direct-test studies by Deutsch *et al.* (Deutsch *et al.*, 2006; Deutsch *et al.*, 2009); Lee and Lee (2010); Miyazaki *et al.* (2012); Wilson *et al.* (2012); and Peng *et al.* (2013) as well as in other studies using smaller numbers of subjects or Web or survey procedures (Bachem, 1948; Sergeant, 1969; Miyazaki, 1988; Profita and Bidder, 1988; Baharloo *et al.*, 1998; Baharloo *et al.*, 2000; Gregersen *et al.*, 1999, 2001; Vanzella and Schellenberg, 2010; Dooley and Deutsch, 2010, 2011).

As shown in Fig. 3, subjects with piano as their primary instrument on the whole outperformed those with different primary instruments. Because piano tones were employed as stimuli, this advantage to pianists could have been due to their greater exposure to piano tones, and so cannot be interpreted with confidence. The prevalence of AP as a function of type of instrumentalist has only rarely been investigated, although many studies on AP possessors have been carried out with pianists exclusively as subjects (cf. Miyazaki, 1989) or with pianists as the largest group of instrumentalists (cf. Lee and Lee, 2010). In a Web-based study, Vanzella and Schellenberg (2010) found that among those who had begun musical training after age 7, those with early training on the piano outperformed other instrumentalists on an AP test even for notes with different timbres. In the present study, pianists outperformed other instrumentalists with age of onset of training ≤ 5, but not those with age-of-onset of training 6–9. The two studies taken together point to a small advantage of early training on the piano for the acquisition of AP. This advantage may be expected, since each key on the piano keyboard produces the identical pitch when struck, and the pitches that are produced increase monotonically as the keyboard is traversed from left to right. In comparison, the violin requires that the performer find an appropriate position on the string to produce the correct pitch, and there are alternative ways of producing most pitches; analogous complexities in pitch production also exist for other non-keyboard instruments. It is also possible that the piano timbre, with its sharp attack, may be particularly conducive to the acquisition of AP. Consistent with this suggestion, it has been found that pitches with piano timbres have been more easily identified, both by pianists and by other instrumentalists, than have those with different instrument timbres (Marvin and Brinkman, 2000; Vanzella and Schellenberg, 2010).

The advantage of white over black key pitches also replicates findings from other studies using a variety of paradigms (Sergeant, 1969; Carroll, 1975; Miyazaki, 1988, 1989, 1990; Takeuchi and Hulse, 1991, 1993; Simpson and Huron, 1994; Marvin and Brinkman, 2000; Vanzella and Schellenberg, 2010; Athos *et al.*, 2007; Bermudez and Zatorre, 2009; Miyazaki *et al.*, 2012). As described earlier, the present black/white key effect cannot be attributed to early training on the piano, since a larger effect was found for orchestral performers than for pianists. However, the effect was here found to correlate well with the frequency of occurrence of notes of different pitch classes in a large sample taken from Western tonal music.

The tendency to name notes a semitone sharp, which was discussed by Ward (1999) and was obtained in a Web-based study by Athos *et al.* (2007), was replicated in the present study, where it was shown to hold for semitone errors but not for errors that were larger than a semitone. However, the present findings ran counter to the hypothesis that the note A serves as a perceptual magnet; rather, they were instead consistent with a general tendency to name notes a semitone sharp.

It should be mentioned that although the tuning used ($A_4 = 440$ Hz) is considered standard, different orchestras worldwide often use tunings that are slightly different from this. It is possible, therefore, that some of the errors may have been influenced by familiarity with slightly different tunings.

In summary, the results of this large-scale study have replicated certain findings that had previously been obtained, such as the high prevalence of AP among tone language speakers, its association with early onset of musical training, the superior performance on white than on black key pitches, the effect of octave range, and the tendency for semitone errors to be on the sharp side. The findings also provided evidence with respect to competing hypotheses concerning the black/white key effect. This effect was here found to be greater among orchestral performers than pianists, indicating that it cannot be attributed to early training on the piano. Further, accuracy in identifying the different pitch classes correlated with their frequency of occurrence in a large sample of music taken from the Western tonal repertoire, indicating that the black/white key effect can be attributed to greater frequency of exposure to white than to black key pitches. In addition, the present findings were inconsistent with the hypothesis that the note A acts as a perceptual magnet but were instead in accordance with the tendency to name notes a semitone sharp. It is expected that additional large-scale studies on populations in which AP is prevalent will further advance our knowledge of this intriguing phenomenon.

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occurrences of each pitch class in the large sample from the classical music repertoire provided by Barlow and Morgenstern (2008).

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