

# Absolute pitch correlates with high performance on interval naming tasks

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(Received 11 April 2011; revised 6 September 2011; accepted 17 September 2011)

Absolute pitch, the rare ability to identify or produce a musical tone without a reference tone, has been shown to be advantageous in some musical tasks; however, its relevance in musical contexts primarily involving relative pitch has been questioned. To explore this issue, 36 trained musicians—18 absolute pitch possessors and 18 non-possessors with equivalent age of onset and duration of musical training—were tested on interval naming tasks requiring only relative pitch. The intervals to be named were either ascending or descending with separation ranging from 1 to 12 semitones and equally involved all 12 pitch classes. Three different conditions were employed; these used brief sine waves, piano tones, and piano tones preceded by a V7-I chord cadence so as to establish a tonal context. The possession of absolute pitch was strongly correlated with enhanced performance on all these tests of relative pitch. Furthermore, no evidence was found that this absolute pitch advantage depended on key, interval size, or musical context.

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PACS number(s): 43.75.Cd [JW]

Pages: 4097–4104

## I. INTRODUCTION

Absolute pitch (AP), the rare ability to name a musical tone in the absence of a reference tone, has attracted the attention of researchers for over a century and generated speculation about its utility in musical processing (Bachem, 1955; Ward, 1999). However, studies exploring the relationship between AP and musical proficiency have yielded mixed results, and this relationship remains unclear. Historically, AP has been revered as a musical gift, possessed by world-class performers and composers (Bachem, 1955), and many musicians seek to develop this skill. Recently, advantages of AP possession have been demonstrated in psychoacoustic tasks involving pitch perception, e.g., in identifying extremely short (5 ms) pure tones or complex tones with missing fundamentals (Hsieh and Saberi, 2007, 2008a, 2009). In addition, a strong positive correlation has been found between performance on an AP test and a melodic dictation task that was derived from music conservatory placement examinations (Dooley and Deutsch, 2010).

In contrast, some researchers have claimed that AP is musically irrelevant or even detrimental to other aspects of musical processing, particularly in tasks requiring only relative pitch (Levitin, 2008; Levitin and Rogers, 2005; Miyazaki, 1993, 1995). The only evidence, to our knowledge, on which this claim is based was provided by Miyazaki (1993, 1995) and Miyazaki and Rakowski (2002), who found Stroop-like interference effects for AP possessors under specific conditions (see following text for a detailed discussion of this work). As pointed out by Dooley and Deutsch (2010), such effects could erroneously be interpreted as due to a general disadvantage of AP possession.

An additional challenge to understanding the potential musical benefits of AP arises from its association with early age of onset of musical training. As Miyazaki and Rakowski (2002) have pointed out, any musical advantage that may be enjoyed by AP possessors could be due to early onset of musical training or long duration of musical training (see also Deutsch *et al.*, 2006, 2009). Any study examining differences between possessors and non-possessors of AP should therefore control for these factors.

The advantage to AP possessors in musical dictation tasks found by Dooley and Deutsch (2010) could in principle be interpreted as deriving from the identification of a series of individual tones rather than from the integrated comprehension of musical relationships. A stronger test of the relevance of AP to performance on musical tasks that could be unrelated to AP possession would be interval identification in which accurate performance depends only on perceiving the relationship between the two pitches comprising the interval. To investigate the relationship between AP and performance on interval naming tasks beyond the identification of each tone separately, 36 trained musicians—18 AP possessors and 18 non-possessors with equivalent age of onset and duration of musical training—were tested with a series of such tasks requiring only relative pitch (RP). Three sets of intervals were used: In the first condition, the intervals were formed by brief sine waves just long enough to give a clear sense of pitch (Hsieh and Saberi, 2007), the second condition consisted of piano tones, and the third condition was identical to the second except that each interval to be named was preceded by a V7-I chord cadence (Miyazaki, 1993) such that the first tone forming each interval would be interpreted as the tonic. The relative contributions of AP possession, age of onset, and duration of musical training to performance on these interval naming tasks were assessed.

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## II. METHOD

### A. Subjects

There were 36 subjects in the study. These were 17 males and 19 females; average age 24.0 years (range: 19–31). Eighteen subjects (9 males, 9 females) were recruited who scored more than 80% correct on a test of AP (see following text); of these, average age was 24.1 years (range: 20–31), average age of onset of musical training was 5.1 years (range: 3–8) and average number of years of formal musical training was 17.1 (range: 10–26). Fifteen of these subjects had been trained on the piano, and three on the violin. Eighteen matched control subjects (8 males, 10 females) were then recruited with equivalent onsets and durations of musical training but who scored less than 20% correct on the AP test; these were of average age 23.8 years (range: 19–31), average age of onset of musical training 5.1 years (range: 3–7) and average number of years of training 17.5 (range: 11–25). *t*-tests confirmed that the two groups of subjects did not differ significantly in age of onset,  $t(34) = -0.14$ ,  $P > 0.05$ , or duration,  $t(34) = 0.28$ ,  $P > 0.05$ , of musical training. As with the AP possessors, 15 of the non-possessors had been trained on the piano, and 3 on the violin. All subjects self-reported normal hearing.

### B. Procedure

All subjects were individually tested. They were first given the test for AP that had been employed in the studies by Deutsch *et al.* (2006, 2009) and Dooley and Deutsch (2010). This test consisted of successive presentations of the 36 tones spanning three octaves from C<sub>3</sub> (131 Hz) to B<sub>5</sub> (988 Hz), and subjects were asked to write down the name of each note (C, F#, E; and so on) after they heard it. All tones were separated from temporally adjacent tones by an interval larger than an octave to minimize the use of relative pitch in making judgments. The tones were piano tones of 500 ms duration with 4.25-s inter-onset intervals; they were presented in three 12-tone blocks with 39-s pauses between blocks. A practice block of four successive tones preceded the three test blocks. No feedback was provided at any time during the test.

The remainder of the experiment consisted of interval naming tasks. These were presented in three different conditions. In all conditions, the subjects were presented with sequential intervals and were asked to write down the name of each interval after they heard it. In each condition, all 144 intervals ranging from a minor second (1 semitone separation) up to an octave (12 semitone separation) were presented. These were based on each of the 12 pitch classes from F# below middle C to the F above, such that each interval size (from 1 to 12 semitone separation) based on each pitch class was included for each of the three versions, and each pitch class occurred equally often. Half of the intervals, with randomly selected orderings, were transposed up one octave, and half, also with randomly selected orderings (independent of the previous selection) were descending rather than ascending. Different random orderings of the intervals were created for each condition, and in all three conditions, the intervals were presented in 12 blocks of 12

intervals with 4-s silence between each trial and 30-s silence between each block. The order of presentation of the three conditions was counterbalanced so that each possible ordering of the three conditions was presented to an equal number of subjects in each group.

The tones in Condition 1 (*sine wave*) provided the minimal pitch information necessary for performing the task (Hsieh and Saberi, 2007). They consisted of 30 ms sine waves, including 5 ms rise and fall times, and so were of minimal duration and free of harmonics. There were no gaps between tones within a pair. Conditions 2 (*piano*) and 3 (*piano with cadence*) each consisted of synthesized piano tones of 500 ms duration, with a 1-s inter-onset interval between tones within a pair. Condition 3 differed from Condition 2 in that a V7-I chord cadence preceded each tone pair, so as to define the first tone of the pair as the “tonic” (see Fig. 1, *piano with cadence*, as an example). Each chord in the cadence was of 1-se duration with no gap between the chords, and there was a 1-s silent interval between the end of each cadence and the first tone of the pair. Following the tests, the subjects filled out a questionnaire regarding the onset and duration of their music education and demographic information.

### C. Instrumentation

For the AP test, the stimuli were piano tones, generated on a Kurzweil K2000 synthesizer tuned to A<sub>4</sub> = 440 Hz and recorded onto a Zoom H2 digital audio recorder. For Condition 1, the stimuli were sine waves generated using Audacity (Version 1.3.6). For Conditions 2 and 3, the stimuli were piano tones, generated with MIDI using GARAGEBAND (Version 3.0.4). All stimuli were stored on a Macbook Pro as WAV files and presented to subjects via Sony MDR-7506 dynamic stereo headphones, at a level of approximately 72 dB SPL.

## III. RESULTS

Figure 2 shows, for each subject, the total percentage of intervals that were correctly labeled across all three conditions as a function of AP possession. As can be seen, AP possession was strongly and positively correlated with performance on the interval naming task,  $r = 0.72$ ,  $P < 0.001$ .<sup>1</sup> This relationship was even stronger when controlling for age of onset and duration of musical training,  $r = 0.77$ ,  $P < 0.001$ . Neither age of onset,  $r = -0.28$ ,  $P > 0.05$ , nor duration of training,  $r = 0.31$ ,  $P > 0.05$ , correlated significantly with the combined interval scores. Performance on the AP and interval naming tasks was not significantly correlated within either group: for the AP possessors,  $r = 0.40$ ,  $P > 0.05$ , or for the AP non-possessors,  $r = 0.00$ ,  $P > 0.05$ .

For both the AP possessors and non-possessors, the performance level in the *sine wave* condition was significantly lower than in either the *piano* or the *piano with cadence* condition: for the AP possessors, *sine wave* vs *piano*,  $t(17) = -20.48$ ,  $P < 0.001$ ; *sine wave* vs *piano with cadence*,  $t(17) = -20.77$ ,  $P < 0.001$ ; for the AP non-possessors, *sine wave* vs *piano*,  $t(17) = -6.53$ ,  $P < 0.001$ ; *sine wave* vs *piano with cadence*,  $t(17) = -7.23$ ,  $P < 0.001$ . The lower performance here was as expected because the tones were of very



FIG. 1. An example interval from each condition, in musical notation. See text for details.

brief duration and free of harmonics, so that the subjects were provided with minimal pitch information. However, there was no significant difference in performance between the *piano* and the *piano with cadence* conditions for either the AP possessors,  $t(17) = -1.58, P > 0.05$ , or the AP non-possessors,  $t(17) = -1.77, P > 0.05$ .

The enhanced performance of the AP possessors relative to the non-possessors was found to persist when each condition was considered separately (Fig. 3). Indeed, this difference between the two groups of subjects was highly consistent across conditions with high correlations between interval scores in the *sine wave* and *piano* conditions,  $r = 0.75, P < 0.001$ ; *piano* and *piano with cadence* conditions,  $r = 0.93, P < 0.001$ ; and *sine wave* and *piano with cadence* conditions,  $r = 0.73, P < 0.001$ . Performance on the AP and interval tests were strongly and significantly correlated taking each condition separately (Fig. 2): *sine wave*,  $r = 0.50, P < 0.01$ ; *piano*,  $r = 0.77, P < 0.001$ ; and *piano*

*with cadence*,  $r = 0.72, P < 0.001$ . Again, these correlations were even stronger when controlling for onset and duration of musical training:  $r = 0.52, P < 0.01$ ;  $r = 0.82, P < 0.001$ ; and  $r = 0.78, P < 0.001$ , for the *sine wave*, *piano*, and *piano with cadence* conditions, respectively. As with the overall interval score, age of onset was not significantly correlated with performance in any of the conditions taken separately:  $r = -0.22, P > 0.05$ ;  $r = -0.26, P > 0.05$ ;  $r = -0.25, P > 0.05$ , for the *sine wave*, *piano*, and *piano with cadence* conditions, respectively. Duration of musical training was not significantly correlated with performance in the *sine wave* or *piano* conditions:  $r = 0.22, P > 0.05$ ;  $r = 0.32, P > 0.05$ , respectively. It was, however, marginally correlated with performance in the *piano with cadence* condition:  $r = 0.36, P < 0.05$ . This last result suggests that musical experience made a small but significant contribution to performance accuracy (accounting for 13% of the variance) when musical context was provided.

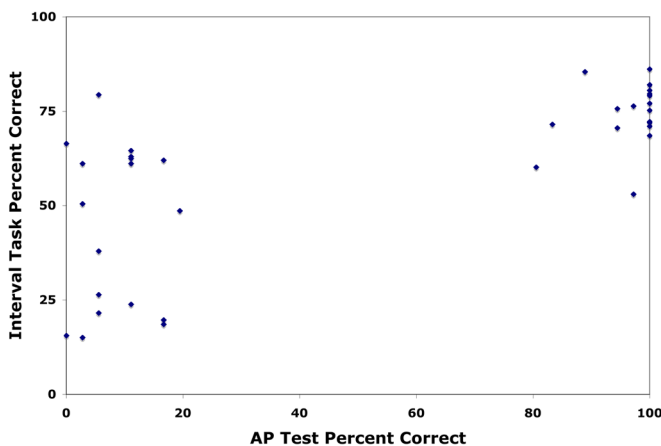


FIG. 2. (Color online) For each subject, overall percent correct on the interval naming tasks as a function of percent correct on the test for absolute pitch.

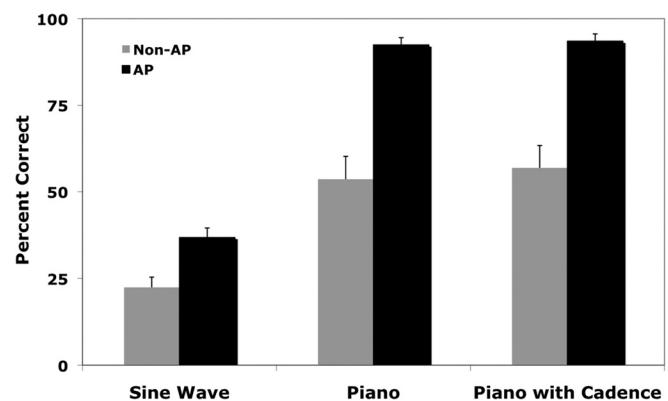


FIG. 3. Mean percent correct in each condition, grouped by AP possession. Error bars represent 1 s.e.

To quantify the extent to which each of these factors predicted overall performance on the interval naming tasks, a multiple regression was performed with AP possession, age of onset of musical training, and years of musical training as predictor variables. AP possession alone accounted for over 50% of all variance in the total scores on the interval naming tasks,  $\beta = 0.72$ ,  $R^2_{\text{adj}} = 0.51$ ,  $F(1, 34) = 37.03$ ,  $P < 0.001$ . Including age of onset of training,  $\beta = -0.18$ , and years of training,  $\beta = 0.21$ , in the overall regression model accounted for an additional 12% of the variance in scores,  $R^2_{\text{adj}}$  change = 0.12,  $F(2, 32) = 5.09$ ,  $P < 0.05$ . These findings strongly indicate that the differences in performance level between the two groups of subjects were associated primarily with their differing degrees of AP possession.

This pattern of results held when each interval condition was considered separately. Repeating this analysis for scores on the *sine wave* condition alone, the factor of AP possession accounted for roughly 25% of all variance,  $\beta = 0.50$ ,  $R^2_{\text{adj}} = 0.23$ ,  $F(1, 34) = 11.35$ ,  $P < 0.01$ . Including age of onset of training,  $\beta = -0.16$ , and years of training,  $\beta = 0.13$ , in the overall regression model accounted for only an additional 3% of the variance in interval scores,  $R^2_{\text{adj}}$  change = 0.03,  $F(2, 32) = 1.58$ ,  $P > 0.05$ . In the *piano* condition, AP possession accounted for over 50% of all variance,  $\beta = 0.77$ ,  $R^2_{\text{adj}} = 0.58$ ,  $F(1, 34) = 49.07$ ,  $P < 0.001$ ; including age of onset of training,  $\beta = -0.13$ , and years of training,  $\beta = 0.25$ , in the overall regression model,  $R^2_{\text{adj}}$  change = 0.10,  $F(2, 32) = 6.46$ ,  $P < 0.01$ . In the *piano with cadence* condition, AP possession again accounted for the majority of all variance,  $\beta = 0.72$ ,  $R^2_{\text{adj}} = 0.50$ ,  $F(1, 34) = 36.12$ ,  $P < 0.001$ ; including age of onset of training,  $\beta = -0.08$ , and years of training,  $\beta = 0.32$ , in the overall regression model,  $R^2_{\text{adj}}$  change = 0.12,  $F(2, 32) = 6.38$ ,  $P < 0.01$ .

Parsing the data further, the influence of pitch class on accuracy in interval naming was considered in relation to that of AP (Fig. 4). A two-way ANOVA was carried out on percentage correct for each of the three conditions with AP possession as a between-subjects factor and the pitch class of the first tone forming each interval (henceforth termed “key”) as a within-subjects factor. For the *sine wave* condition, the main effect of AP was significant,  $F(1,34) = 12.76$ ,  $P = 0.001$ ,  $\eta^2 = 0.27$ ; the main effect of key was significant,  $F(11, 374) = 6.88$ ,  $P < 0.001$ ,  $\eta^2 = 0.17$ ; and the AP  $\times$  key interaction was not significant,  $F(11, 374) = 1.63$ ,  $P > 0.05$ . For the *piano* condition, the main effect of AP was significant,  $F(1,34) = 30.59$ ,  $P < 0.001$ ,  $\eta^2 = 0.47$ ; the main effect of key was significant,  $F(11, 374) = 3.51$ ,  $P < 0.001$ ,  $\eta^2 = 0.09$ ; and the AP  $\times$  key interaction was not significant,  $F(11, 374) = 1.04$ ,  $P > 0.05$ . For the *piano with cadence* condition, the main effect of AP was significant,  $F(1,34) = 28.96$ ,  $P < 0.001$ ,  $\eta^2 = 0.46$ ; the main effect of key was not significant,  $F(11, 374) = 1.39$ ,  $P > 0.05$ ; and the AP  $\times$  key interaction was not significant,  $F(11, 374) = 1.62$ ,  $P > 0.05$ . In addition, *post hoc t*-tests comparing the overall accuracy of possessors and non-possessors for each pitch class separately were significant at  $P < 0.001$  for all 12 keys. In sum, the significant advantage of AP possession across all three conditions was not related to the pitch classes of the tones of which the intervals were comprised.

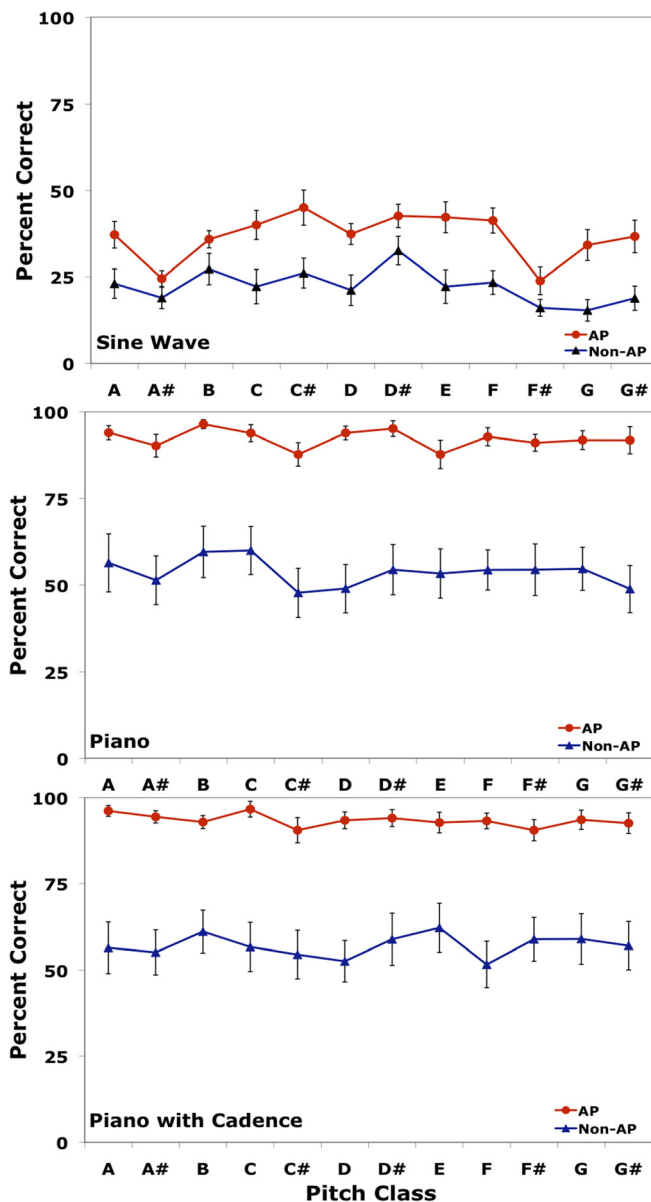


FIG. 4. (Color online) Mean percent correct in each condition, grouped by AP possession and pitch class of the first tone of each interval. Error bars represent 1 s.e.

This analysis was repeated, testing the within-subjects variable of interval size rather than key. As can be seen in Fig. 5, the overall performance of AP possessors exceeded that of non-possessors for all interval sizes; however, the degree of this difference varied by interval. For the *sine wave* condition, the main effect of AP was significant,  $F(1,34) = 12.66$ ,  $P = 0.001$ ,  $\eta^2 = 0.27$ ; the main effect of interval size was significant,  $F(11, 374) = 17.83$ ,  $P = 0.001$ ,  $\eta^2 = 0.34$ ; and the AP  $\times$  interval size interaction was marginally significant,  $F(11, 374) = 1.83$ ,  $P = 0.05$ ,  $\eta^2 = 0.05$ . As one exception, the performance of the AP possessors at the octave interval for short duration sine waves did not exceed that of the AP non-possessors. Instead the AP possessors showed a tendency to misidentify the octave as a major or minor 7th. In contrast, the errors of identification among the AP non-possessors in this subcondition were more widely distributed across intervals. Specifically, when

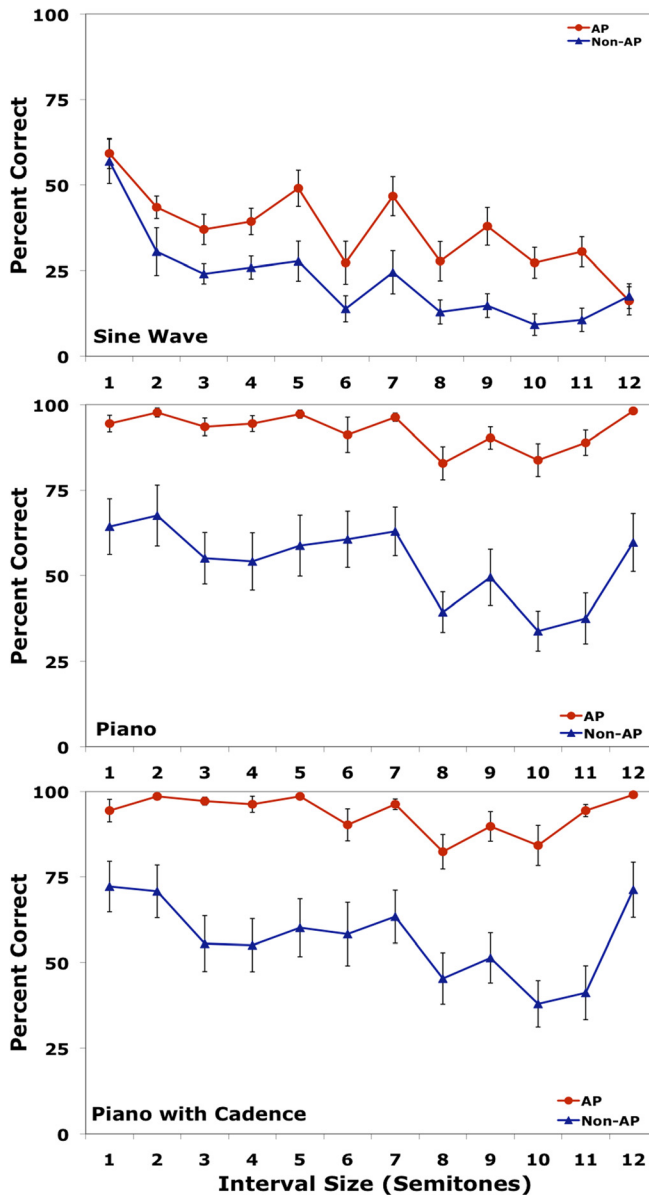


FIG. 5. (Color online) Mean percent correct in each condition, grouped by AP possession and interval size. Error bars represent 1 s.e.

presented with octave intervals, AP possession, compared with non-possession, was significantly negatively correlated with distance between judged and actual interval size,  $r = -0.28$ ,  $P < 0.001$ . We also note that for the AP possessors, performance in this condition was significantly lower at the octave than at the major 7th,  $t(17) = 2.90$ ,  $P = 0.01$ , while for the AP non-possessioners the difference in performance at these two intervals was nonsignificant,  $t(17) = -1.41$ ,  $P > 0.05$ . As a possible explanation, AP possessors may be more sensitive to the octave stretch phenomenon where no harmonic cues are provided (Burns, 1999; Terhardt, 1971), although this intriguing result awaits further investigation.

For the *piano* condition, the main effect of AP was significant,  $F(1,34) = 31.04$ ,  $P < 0.001$ ,  $\eta^2 = 0.48$ ; the main effect of interval size was significant,  $F(11, 374) = 10.21$ ,  $P < 0.001$ ,  $\eta^2 = 0.23$ ; and the AP  $\times$  interval size interaction

was significant,  $F(11, 374) = 2.05$ ,  $P < 0.05$ ,  $\eta^2 = 0.06$ . For the *piano with cadence* condition, the main effect of AP was significant,  $F(1,34) = 28.86$ ,  $P < 0.001$ ,  $\eta^2 = 0.46$ ; the main effect of interval size was significant,  $F(11, 374) = 9.00$ ,  $P < 0.001$ ,  $\eta^2 = 0.21$ ; and the AP  $\times$  interval size interaction was significant,  $F(11, 374) = 2.64$ ,  $P < 0.01$ ,  $\eta^2 = 0.07$ .

Although not of primary interest in the present investigation, the overall effects of interval size are worth considering. As can be seen (Fig. 5), there is a negative relationship between interval size and interval naming accuracy, and in fact this correlation is significant taking overall scores across groups and condition,  $r = -0.77$ ,  $P < 0.01$ . This may be due in part to the greater frequency of occurrence of smaller intervals in Western music (Vos and Troost, 1989). Furthermore, it can be seen that consonance was also a contributing factor to interval naming accuracy, such that subjects were overall more likely to correctly identify intervals separated by 7 semitones (perfect 5th) and 12 semitones (octave) than smaller but less consonant intervals. Specifically, *post hoc* paired samples *t*-tests revealed overall accuracy to be significantly greater for 12 semitones than for 11 semitones (major 7th),  $t = 3.51$ ,  $P = 0.001$ , 10 semitones (minor 7th),  $t = 4.29$ ,  $P < 0.001$ , and 8 semitones (minor 6th),  $t = 3.17$ ,  $P < 0.01$ ; similarly, overall accuracy was significantly greater for 7 semitones than for 6 semitones (tritone),  $t = 2.68$ ,  $P < 0.05$ . This pattern is consistent with results from previous studies examining identification accuracy for different interval sizes (Killam *et al.*, 1975; Rakowski, 1990), and Rakowski (1990) has noted the influence of both interval size and consonance in predicting accuracy of interval recognition and reproduction.

Combining all conditions, the comparatively small but significant interaction between AP possession and interval size most likely reflects the variation in accuracy for all subjects across interval sizes, coupled with floor and ceiling effects, such that between-group differences were compressed on intervals with the highest and lowest accuracy rates (Fig. 5). *Post hoc t*-tests were performed to compare the overall accuracy of AP possessors and non-possessioners for each interval size. The expected AP advantage was confirmed for all interval sizes:  $P < 0.01$  for intervals separated by 1 semitone,  $P = 0.001$  for separations of 2 and 6 semitones, and  $P < 0.001$  for all other interval sizes. Thus the overall accuracy of AP possessors was significantly greater than that of non-possessioners for every interval size tested.

One issue that arises concerns the ethnic and linguistic backgrounds of the subjects because persons of East Asian descent and those who are speakers of tone language are more likely to be AP possessors than are those who are Caucasian and who speak non-tone languages (Deutsch *et al.*, 2006, 2009; Gregersen *et al.*, 1999, 2000; Lee and Lee, 2010). Considering ethnicity, 13 of the AP possessors were of East Asian descent, and 5 were Caucasian. These two subgroups of AP possessors did not differ significantly in overall performance on interval identification,  $t(16) = 1.19$ ,  $P > 0.05$ . In addition, 5 of the non-possessioners were of East Asian descent, and 10 were Caucasian (the other three subjects in this group fell into neither category). Again, the two subgroups of non-possessioners

did not differ significantly in their overall performance here,  $t(13) = 0.62$ ,  $P > 0.05$ .

Concerning tone language, 8 of the AP possessors were fluent tone language speakers, while the other 10 AP possessors were non-tone language speakers. These subgroups did not differ significantly from each other in overall performance on interval identification,  $t(16) = 0.60$ ,  $P > 0.05$ . Of the non-possessors, 3 subjects were partially fluent tone language speakers, and the other 15 were non-tone language speakers. These subgroups did not differ significantly from each other on interval identification either,  $t(16) = 0.47$ ,  $P > 0.05$ . This lack of a difference depending on language is interesting, because Pfordresher and Brown (2009) had found that tone language speakers outperformed non-tone language speakers in an interval discrimination task. It is difficult to evaluate the relationship of this finding to those of the present study, however, since the subjects tested by Pfordresher and Brown (2009) had had little or no musical training.

#### IV. DISCUSSION

The results of this study strongly support the hypothesis that AP possession is associated with enhanced performance on musical tasks requiring only RP: The factor of AP possession alone accounted for the majority of all variance in performance on our interval tasks. Because AP possession is associated with early musical training (Miyazaki and Rakowski, 2002) it is important to point out that the strength of the relationship between AP and interval naming found here held even controlling for age of onset and duration of musical training. Our finding of uniformly high performance among AP possessors therefore adds to the growing body of research documenting advantages of AP possession in musical and psychoacoustic tasks (Dooley and Deutsch, 2010; Hsieh and Saberi, 2007, 2008a, 2009).

Our findings run contrary to the claim that AP is musically irrelevant or disadvantageous, particularly in matters of RP (Levitin, 2008; Levitin and Rogers, 2005; Miyazaki, 1993, 1995). This discrepancy can be reconciled by considering the results of Miyazaki and Rakowski (2002). Consistent with the present findings, these authors identified a significant AP advantage for accuracy in judgment of both tonal and atonal melodies when these were played to subjects in the correct key as written; however, they obtained a moderate negative correlation between AP score and judgment accuracy for transposed melodies, which were presented at different pitch levels than as written (although this correlation was significant only for atonal melodies). A likely explanation for the apparent inconsistency between our findings and those of Miyazaki and Rakowski is that AP possessors are subject to Stroop-like interference effects in artificial situations (Hsieh and Saberi, 2008b; Miyazaki and Rakowski, 2002; Roberts and Hall, 2008; Stroop, 1935; Takeuchi and Hulse, 1993).

Similarly, Miyazaki (1993, 1995) found an apparent disadvantage of AP possession in naming out-of-tune intervals, and this can also be interpreted as resulting

from Stroop-like interference. Two methodological factors in particular are likely to have contributed to such interference here. One was the use of detuned intervals in which the relative distance between the tones comprising the intervals conflicted with the interval formed by the pitch classes of the tones. For example, the correct response for a C 40 cents sharp and an E 40 cents flat would be a minor third; however, an AP possessor using the identities of the tones to determine interval size could be led astray, rounding off to a C and an E and then concluding that the interval formed a major third. As another factor, these subjects had been trained using a fixed do system and yet were required to name intervals using movable-do labels the meanings of which conflicted with their fixed-do meanings for all reference pitches other than C. For example, a response key labeled “mi” was intended in these experiments to signify a major 3rd; yet it also signified the note E for these subjects. However, the label “mi” in these studies actually referred to E only when the reference note was C and not when it differed from C. It should be pointed out that in these studies the performance of AP possessors dropped below that of non-possessors only in the non-C reference conditions in which such Stroop-like interference would be in effect (see also Renninger *et al.*, 2003; Itoh *et al.*, 2005). Also of note, Terhardt (1983) has shown that interval identification by AP non-possessors was substantially poorer when the first note comprising the interval was varied than when it was fixed.

The findings of the present study indicate that AP is advantageous in interval naming across all keys and interval sizes when the stimuli are limited to the standard tunings typically encountered in Western tonal music. Furthermore, the consistency of the AP advantage found across all three conditions employed in the study emphasizes the generality of these findings. In addition, the high correlation between individual scores on the *piano* and *piano with cadence* conditions,  $r = 0.93$ ,  $P < 0.001$ , and the lack of significant difference between performance levels in these conditions for both AP possessors,  $t(17) = -1.58$ ,  $P > 0.05$ , and non-possessors,  $t(17) = -1.77$ ,  $P > 0.05$ , confirm that these results did not depend on the presence or absence of musical context (Fig. 3). More specifically, inserting a V7-I chord cadence before the interval to be named (a procedure also used by Miyazaki (1993) to provide musical context) did not erase the sizable AP advantage in interval naming across all 12 keys (Fig. 4) and all 12 interval sizes tested (Fig. 5).

Also of interest in the present study was the possible effect of tone duration on contributions of AP possession to interval naming accuracy. The tones used in the *sine wave* condition were designed to last just long enough to give a clear sense of pitch (Hsieh and Saberi, 2007). Although the raw scores in this condition were lower for all subjects (Fig. 3), the AP advantage proved no greater as a proportion (mean percentage correct was 64% greater for AP possessors than non-possessors) than in the *piano* (72%) or *piano with cadence* conditions (64%). This consistent difference between AP possessors and non-possessors across all three conditions indicates that the superior performance of AP

possessors was evident for all timbres and tone durations tested.

While the large role played by AP in predicting performance on the interval naming tasks was surprising relative to the comparatively small effects of onset and duration of musical training, we should note that conclusions drawn from the present data are limited to the range of the characteristics of the subjects included in the study. Specifically, for the AP and non-AP groups to be compared appropriately, the age of onset of musical training for all subjects ranged from ages 3 to 8, and the duration of training ranged from 10 to 26 years. These other factors may play a larger role in predicting proficiency in performing interval naming and other musical tasks for subject populations that include wider ranges of musical experience.

Clearly related to the effects of AP possession on perception and cognition are the means by which AP is acquired. Although outside the scope of this article, a number of potential factors have been identified, including tone language fluency (Deutsch *et al.*, 2006, 2009), physiological differences (Keenan *et al.*, 2001; Loui *et al.*, 2010; Schlaug *et al.*, 1995; Schulze *et al.*, 2009), genetics (Theusch *et al.*, 2009), and early music education (Miyazaki and Ogawa, 2006); indeed, it appears that the potential for developing AP is present in infancy (Saffran and Griepentrog, 2001).

It is also important to note that while all AP possessors performed well on the interval tasks in this study (an overall mean of 74% correct and no scores below 50%), some non-possessors also performed well (a mean of 44%, and one even scored above 70% correct). AP is therefore not necessary for successful performance on interval naming as has also been shown for musical dictation by Dooley and Deutsch (2010), even though it appears to be associated with a substantial advantage in these tasks. Anatomical and functional imaging findings have revealed underlying differences in the way AP possessors and non-possessors perceive and encode pitch, and these AP advantages may derive from fundamentally different perceptual or cognitive processes (Loui *et al.*, 2010; Oechslin *et al.*, 2009; Schulze *et al.*, 2009; Zatorre *et al.*, 1998). More research is needed to explore exactly how AP possession confers such a strong advantage in RP tasks and also in which other domains of musical proficiency it might prove beneficial.

<sup>1</sup>Because normality assumptions were not met for the raw data based on the Shapiro–Wilk test for interval test scores ( $P < 0.001$ ), years of musical training ( $P < 0.05$ ), and age of onset of musical training ( $P < 0.01$ ), all variables were rank-transformed, and all reported correlation and regression statistics are based on the rank-transformed data. Nonetheless, all patterns of significance for the raw data were nearly identical to those reported.

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