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Intersecting Factors Lead to Absolute Pitch Acquisition That is Maintained in a "Fixed *do*" Environment

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The skill of absolute pitch (AP) has been proposed as an ideal paradigm for investigating the complex relationships that exist between the genome and its expression at a cognitive and behavioral level (the phenotype). Yet despite this, we still have limited understanding of the early conditions that might be necessary or sufficient for development of this skill, and the influence of the current music environment has not been explored. To investigate these issues we undertook a detailed characterization of the early and current music environment of 160 musicians, and then identified factors predictive of varying extent of AP ability. The results demonstrate a similar contribution of past and present environmental influences, with a combination of factors (rather than any given factor) most salient in AP musicians. The novel finding for the role of the current environment suggests that auditory processing models emphasizing plasticity effects are relevant to AP ability.

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Key words: pitch perception, absolute pitch, phenotype, environmental factors, auditory plasticity

While the majority of humans possess the ability to correctly identify familiar environmental sounds with ease, a much smaller number possess the ability to identify single pitches, otherwise known as absolute pitch (AP). The relatively rare nature of this ability has intrigued researchers for over 100 years, with early studies delineating the extent of the skill in select individuals (Bachem, 1937, 1940). More recent research has investigated its expression in the broader population, with a view to uncovering its genetic basis (Athos et al., 2007; Baharloo, Johnston, Service, Gitschier, & Freimer, 1998; Gregersen, Kowalsky, Kohn, & Marvin, 1999). Intrinsic to both approaches is the view that AP arises from the interaction of genetic, maturational, and experiential factors (Zatorre, 2003). Because AP is a relatively circumscribed skill that can be easily measured, this makes it an ideal paradigm for investigating how these factors may intersect in cognitive development generally (Baharloo, Service, Risch, Gitschier, & Freimer, 2000; Zatorre, 2003). Yet despite this, we still have limited understanding of the conditions that might be necessary or sufficient for the development of AP (Bermudez & Zatorre, 2009). Even less understood is the relevance of an individual's current environment for the ongoing expression or maintenance of the skill.

Within the broader pitch processing literature, considerable debate has surrounded the relative contributions of spectral pattern matching and temporal waveform processing to neurocognitive mechanisms of pitch processing (de Cheveigné, 2005). The lack of an agreed model of pitch processing per se has likely contributed to the range of theories proposed to account for AP ability, including an early learning theory, an unlearning theory, an innate theory, and a precategorical theory, all of which have received varying levels of support in the literature (cf. Chin, 2003; Deutsch, 2002; Ross, Gore & Marks, 2005; Saffran & Griepentrog, 2001; Takeuchi & Hulse, 1993; Zatorre, 2003). Of particular relevance to pitch naming by musicians, Levitin (1994; Levitin & Rogers, 2005) proposed a hierarchical, two-component model of AP that first involves the absolute representation of pitch, followed by a second component of pitch labeling, typically but not exclusively using a verbal code (Zatorre & Beckett, 1989). This second component is thought to be acquired during a critical or sensitive period of development through associations between pitches and labels, allowing tones to be organized into nominal categories (Zatorre, 2003). In AP possessors the two components are presumably integrated, creating unique AP templates (Levitin & Rogers, 2005).

It has been argued that early music training is not a necessary condition for the expression of AP, nor is training during a sensitive period sufficient for its development (Brown, Sachs, Cammuso, & Folstein, 2002; Gregersen, Kowalsky, Kohn, & Marvin, 2000). Even so, research

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commonly places the sensitive period in the preschool years (ages 3-7), prior to the shift from absolute to relational processing that is evident across a range of cognitive domains (see Chin, 2003, for a review). A modal acquisition age of 6 years has been proposed as modeled by a gamma function, based on data from more than 600 musicians (Levitin & Zatorre, 2003). In these data, there was a sharp decline in onset age after 7 years (Baharloo et al., 1998; Chin, 2003). Since a sensitive period refers to a central tendency at which individuals pass through a particular developmental phase (Levitin & Zatorre, 2003), it can be expected that individuals will develop AP outside this period, with an upper age limit estimated at 9-12 years (Levitin & Zatorre, 2003; Zatorre, 2003). This upper limit may be extended in individuals with atypical development such as Williams syndrome, Autism Spectrum Disorders, or congenital blindness, highlighting the importance of developmental factors such as mental age and cognitive style (Chin, 2003). Also significant is the nature of training undertaken during the sensitive period, with healthy AP possessors more commonly exposed to early training that emphasizes consistent tone-label mappings or a "fixed *do*" pedagogy such as the Suzuki or Yamaha methods, as compared with traditional Western "movable *do*" training that promotes relative pitch [RP] processing (Gregersen et al., 2000; Vitouch, 2003).

A genetic predisposition has been proposed as necessary (Athos et al., 2007; Chin, 2003), with self-reported AP possessors four times more likely to have a family history of AP compared to non AP possessors (Baharloo et al., 1998). To examine the extent to which familial aggregation may reflect genetic predisposition as opposed to shared family experience of early music training, Baharloo and colleagues (1998, 2000) employed strict criteria to define an "AP-1 phenotype," comprising only those individuals who scored at least three standard errors above the mean score of a randomized group of musicians with or without self-reported AP. This showed that AP-1 occurs at an estimated rate of 2.9% in the population of individuals with early music training, compared to a significantly increased rate of 26.2% among early trained siblings of AP-1 probands (Baharloo et al., 2000). These rates were based on conservative estimates of sibling recurrence yet appear significantly elevated compared with the population prevalence after control for early music training. Thus, they support a strong role for genetic influences, and suggest that aggregation in families may follow a pattern of autosomal dominant transmission with incomplete penetrance (Barharloo et al., 2000; Gregersen et al., 1999; Profita & Bidder, 1988).

Genetic research has highlighted the need for reliable identification of specific AP phenotypes (such as AP-1) for successful gene mapping studies (Barharloo et al., 2000; Gregersen et al., 1999). This is consistent with the view that there may be variable expression of AP ability that falls along a continuum, rather than AP being an "all-or-none" ability. Less developed forms include AP for specific music notes (quasi-absolute pitch; QAP) or latent forms, such as absolute pitch memory for popular songs evident within the broader population (Bachem, 1937; Deutsch, 2002; Halpern, 1989; Levitin & Rogers, 2005; Terhardt & Ward, 1982). Behavioral studies have shown that QAP can be facilitated by a range of auditory cues, including timbre, key color (black or white notes of the piano), and pitch register or height (Athos et al., 2007; Bachem, 1955; Takeuchi & Hulse, 1993). This implies that QAP may be based on a limited number of AP templates that may be more bound to contextual cues present during perceptual encoding. Supporting this, recent neuroimaging research indicates that structural and functional brain differences may underpin different forms of AP ability, with QAP associated with changes in right temporal and frontal regions that may reflect greater processing of spectral pitch cues, and engagement of working memory for pitch identification (Wilson, Lusher, Wan, Dudgeon, & Reutens, 2009).

Understanding variability in the expression of AP is essential for accurate characterization of its behavioral phenotypes and elucidating their neurological and genetic bases. More generally, this promises insights into the plasticity of auditory knowledge formation and representation. Because variability in AP expression potentially reflects a range of factors and the relative contribution of these factors is unknown, we first targeted key factors identified across the research literature relevant to a range of AP theories, and assessed their relative contribution to the expression of different forms of AP ability. We then investigated the relevance of the current music environment, as this has not been previously addressed. Based on past research we hypothesized that compared to musicians with QAP or RP, musicians with AP would be significantly more likely to have: (1) a genetic predisposition for AP as based on the report of a family history, (2) commenced training during the sensitive period (3-7 years), and (3) early exposure to a pedagogy that emphasized consistent tone-label mappings (early training "fixed *do*"), with the combination of all three factors most likely in musicians with AP.

Method

PARTICIPANTS

The sample comprised 160 musicians recruited from the community and tertiary institutions via advertisements placed in local newspapers and on student notice boards, targeting students undertaking tertiary music studies. We tested the pitch naming ability of the musicians in an auditory laboratory (see "Measures"), and on this basis they were assigned to one of three groups: musicians with AP, musicians with QAP, or musicians with RP. Demographic information was obtained from the Survey of Musical Experience (see "Measures"), with Table 1 showing the background characteristics of the musicians assigned to the AP, QAP, and RP groups. Importantly, participants did not differ for sex, age, education, region of birth, or cultural background, nor was there a difference in their report of early exposure to music, specifically singing in the home ($p > .05$ for all comparisons). Eleven percent (11%) of the entire sample spoke a tone language (namely Mandarin or Cantonese), and consistent with previous research (Deutsch, Dooley, Henthorn, & Head, 2009), this was significantly higher in AP compared to QAP and RP musicians, $\chi^2(2) = 7.58$, $p = .023$. The study was approved by the Human Research Ethics Committee of The University of Melbourne and all participants gave written, informed consent.

MEASURES

Previous music experience. A detailed characterization of the early and current music environment of participants was obtained using a face-to-face interview, the Survey of Musical Experience. This is a standard interview that was developed to assess the onset, amount, and type of music training (Wilson, Pressing, Wales & Pattison, 1999). It was designed to elicit qualitative and quantitative information about an individual's early music environment, including the degree of music exposure in the home, music behavior (including AP) in other family members, access to music instruments, and the nature of early music instruction and performance, including the study of music as part of general schooling. The interview canvasses markers of music proficiency such as the length of training on particular instruments, the ability to read or write music, training in music theory or composition, the presence of any formal music qualifications (e.g., attainment of music grades), and the current number and type of public performances or pieces composed. It also assesses preferred music styles and the extent of current music listening. In addition to profiling each participant's early music environment, this information allowed accurate delineation of the age of onset of formal music training (relative to the sensitive period of 3-7 years), the type of early training received (pedagogy emphasizing a fixed or moveable *do*), and the presence of a family history of AP based on the report of AP in first-, second-, or third-degree relatives. Previous research has indicated

TABLE 1. Background Characteristics of the AP, QAP, and RP groups (N = 160)

	AP (*n* = 43)	QAP (*n* = 49)	RP (*n* = 68)
Pitch naming score (mean, range) [a]	48.7 (45-50)	30 (10-44)	2.3 (0-8)
Males (n, %)	13 (30%)	22 (45%)	29 (43%)
Age (mean yrs, range) [b]	23.9 (17-61)	26.7 (18-68)	26.3 (18-54)
Education (mean yrs, range) [c]	15.9 (11-24)	15.8 (12-35)	16.3 (13-30)
Region of birth (n,%) [b, d]			
- Australia/New Zealand	22 (51%)	28 (58%)	42 (62%)
- Northeast/Southeast Asia	18 (42%)	14 (29%)	18 (26%)
- Europe/UK/USA	3 (7%)	6 (13%)	8 (12%)
Cultural background (n,%) [b, d]			
- Northeast/Southeast Asian	19 (44%)	15 (31%)	20 (29%)
- Nonasian	24 (56%)	33 (69%)	48 (71%)
First language tone language (n,%) [e]	9 (21%)	5 (10%)	3 (4%)*
Early exposure to singing in home (n, %) [c]			
- never/rarely	3 (7%)	5 (11%)	4 (6%)
- sometimes	11 (26%)	6 (13%)	9 (13%)
- often/everyday	29 (67%)	36 (76%)	55 (81%)

[a] Machine malfunction resulted in one case of reclassification for an AP female.
[b] There was one case of missing data for the QAP males.
[c] There were two cases of missing data for the QAP males.
[d] Given the finding of a higher incidence of AP in East Asian music students (Gregersen et al., 1999), participants of Northeast or Southeast Asian background were compared to all other participants using chi-squared analysis. Results showed no significant difference in the proportion of AP, QAP, or RP musicians for region of birth, $\chi^2(2) = 3.06$, $p = .217$, or cultural background, $\chi^2(2) = 2.79$ $p = .248$.
[e] This included individuals with a first (native) language of Mandarin or Cantonese. In both the AP and QAP groups, this proportion is much greater than the estimated 3.5% of individuals who reported speaking Mandarin or Cantonese at home in the 2006 Australian Consensus, as published by the Australian Bureau of Statistics for the Melbourne region (www.censusdata.abs.gov.au).
* $p \leq .05$

that the reliability of a reported family history of AP is greater than the reliability of self-reported AP, particularly when strict criteria for AP are employed, with more than 90% of siblings reported to possess AP testing positively for the AP-1 phenotype (Barharloo et al., 2000). The Survey of Musical Experience was also used to collect demographic information from the participants.

Pitch naming task. In accordance with our previously published methods (Wilson et al., 2009), we tested AP ability using a randomized series of 50 synthesized complex tones that each musician was required to identify without feedback of the accuracy of their responses. We used a piano timbre to capture variability in the expression of AP, as our research has shown that this timbre is able to detect lesser forms of pitch naming ability (QAP) that are more stimulus-bound (Wilson et al., 2009). A piano timbre is also an ecologically valid and highly familiar sound that is typically present in both past and current music environments, allowing the relative contribution of past and current environmental factors to be adequately explored.

Tones were selected from the equal tempered scale, ranging from C2–C5 (concert pitch A4 440 Hz) and proportionally distributed across the black and white notes of the piano. Each tone had a duration of 500 ms, followed by an interval of 2.5 s response time (1 stimulus = 3 s). This short response time was used to minimize accurate pitch naming based on relative pitch judgements. The tones were synthesized using the "stereo grand" piano timbre of a Yamaha S80, 88-note fully weighted keyboard, linked to a G4 Apple Macintosh computer (Mac OS 8.6). Pro Tools LE software (version 5.0) was used to assemble the stimuli, which were binaurally presented to the musicians via loud speakers in free field at a comfortable listening level. Participants verbally identified the tones, typically using their music note names (pitch chroma). Previous research has shown that octave errors are common and thus accurate octave classification was not required, whereas scoring of semitone errors has been more varied (Takeuchi & Hulse, 1993). Consistent with the use of strict criteria for estimating familial aggregation of AP, we coded semitone errors as incorrect and classified musicians a priori as having AP if ≥ 90% of the tones were correctly identified. Musicians identifying ≤ 20% of tones were considered to lack AP (RP musicians), while those falling in between were classified as QAP (see Table 1).

PROCEDURE

All testing was undertaken in an auditory laboratory and took approximately 60 min per participant. Musicians initially underwent audiometry for detection of significant hearing loss, followed by administration of the Survey of Musical Experience and the pitch naming task. This order of administration was chosen to maximize the period of time for which the experimenter was blind to AP status (as based on pitch naming scores).

DATA ANALYSIS

Analyses were performed using PASW Statistics 18 (PASW Statistics, 18.0.0), with $p \leq .05$ (two-tailed) set as the criterion of statistical significance. Chi-square analyses were first used to test the study hypotheses. The number and combination of early environmental factors reported by each individual were also assessed using the nonparametric Kruskal-Wallis test with group as the independent variable. Factors were rank ordered, with three combinations of one factor, three combinations of two factors, and one combination of three factors or no factors, producing a score ranging between 0-7 for the analysis. A multiple discriminant function analysis [MDFA] was then performed to assess the relative contribution of variables identified as significant in the above analyses. As is standard for MDFA, additional exploratory analyses of associations between group membership, the early and current music environment, and music proficiency were performed to identify the range of music variables potentially relevant to predicting pitch naming ability. In this first stage of analysis, significant associations were tested using chi-square analyses for categorical data and one-way ANOVA for continuous data with posthoc contrasts performed using Tukey's Honestly Significant Difference test to adjust for multiple comparisons or Tamhane's T2 where equal variance was not assumed. MDFA was then used to assess the statistical robustness and relative impact of the variables found to be significant in the first stage for predicting AP, QAP, and RP group membership. Prior probabilities of group membership were computed from group sizes to reflect the lower incidence of AP and QAP in the general population.

Results

CHARACTERIZING PITCH NAMING ABILITY

Figure 1A shows a scatterplot of the total scores achieved by the musicians classified a priori as AP, QAP, or RP on the pitch naming task. Consistent with previous studies, there was a broad spread of performance across the entire range of the task (0-50), with evidence of two clusters of musicians at either end of the range (Athos et al., 2007). These two clusters largely corresponded to musicians with high level AP (≥ 90% accuracy) and those with RP (≤ 20% accuracy), with an even spread of musicians falling between these two extremes (classified as QAP). This even spread falling along the spectrum of ability below

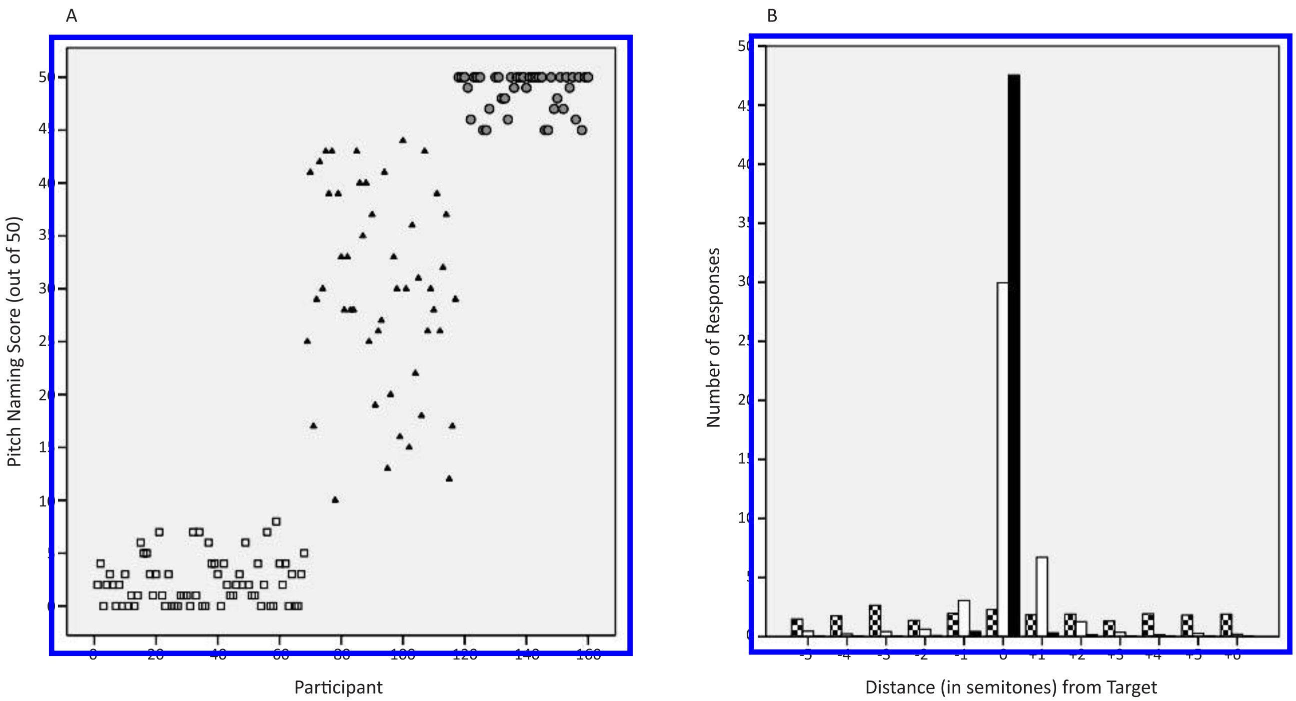

FIGURE 1. Performance on the pitch naming task for AP, QAP, and RP musicians. (A) Scatterplot of the total pitch naming score (out of 50) achieved by each participant. AP (grey circles); QAP (black triangles); RP (white squares). (B) Histogram of the accuracy of pitch naming for the AP (black), QAP (white), and RP (checked) musicians, with mean frequency shown for each deviation (in semitones) from the target pitch. Missed or "don't know" responses: RP 55.6%; QAP 12.5%; AP 0.4%.

the strict cut-off for AP supports capture of variable expression of pitch naming under the QAP classification. Figure 1B shows the distribution of response deviations from the target pitch (in semitones) for the AP, QAP, and RP musicians. AP musicians showed minimal deviation from the target pitch compared to the remaining two groups, indicative of high level AP in these musicians. In contrast, RP musicians were largely operating at chance levels, with many missed responses and a spread of errors across the entire distribution. QAP musicians again performed between these two extremes.

CHARACTERIZING THE EARLY MUSIC ENVIRONMENT OF AP MUSICIANS

In support of hypothesis 1, the expected difference in genetic predisposition was observed, with AP musicians significantly more likely to report a family history of AP compared to QAP or RP musicians, $\chi^2(2) = 8.71$, $p = .013$ (see Table 2). Confirming earlier findings, age of onset of music training also differed, $F(2, 156) = 15.98$, $p < .001$, partial $\eta^2 = .17$, with AP musicians reporting an earlier onset than QAP musicians (contrast estimate = 1.40, $p = .005$), who in turn reported an earlier onset than RP musicians (contrast estimate = 1.20, $p = .008$). Related to this, there was a significant association between the commencement of music training during the sensitive period of 3-7 years and pitch naming ability, $\chi^2(2) = 11.60$, $p = .003$. While the majority of musicians commenced training during this period, this was most evident in the AP musicians, supporting hypothesis 2 (Table 2).

In support of hypothesis 3, the type of early music training to which the groups were principally exposed showed significant differences, with AP musicians having the greatest exposure to pedagogies that emphasized a fixed *do*, $\chi^2(2) = 15.41$, $p < .001$ (Table 2). Related to this, the majority of AP musicians started music training on an instrument that emphasized a fixed, categorical pitch, such as the piano (here called a "fixed *do* instrument" for ease), while a small number learnt violin (a "movable *do* instrument"; Table 2). Although there was a predominance of early pianists in the QAP and RP groups, there was considerably greater heterogeneity of first instruments, including strings, woodwind, brass, and voice.

THE INTERACTION BETWEEN A FAMILY HISTORY OF AP AND EARLY ENVIRONMENTAL FACTORS

The hypothesis that a combination of early environmental factors and genetic predisposition would be

TABLE 2. Music Characteristics of the AP, QAP, and RP groups (N = 160)

	AP (*n* = 43)	QAP (*n* = 49)	RP (*n* = 68)
Family history of AP (n, %) [a]	14 (35%)	7 (15%)	8 (13%)*
Onset of training (mean yrs, range) [b]	4.4 (2-10)	5.8 (2-13)	7.0 (3-15)***
Training in sensitive period (n, %) [b]	42 (98%)	39 (81%)	49 (72%)**
Early training fixed *do* (n, %) [c]	18 (45%)	12 (27%)	7 (11%)***
First instrument fixed *do* (n, %) [b, d]	38 (88%)	36 (75%)	50 (74%)
Main instrument fixed *do* (n, %) [d, e]	34 (79%)	28 (60%)	29 (43%)***
Training main instrument (mean yrs, range) [a]	14.4 (1-28)	12.3 (2-20)	7.7 (0-16)***
Training in music theory (mean yrs, range) [a, f]	7.1 (1-17)	7.3 (0-17)	4.9 (0-20)**
Hours practice per week (mean, range) [g]	14.3 (2-42)	11.3 (1-36)	8.8 (0-60)**
Hours music listening per week (mean, range) [a]	22.4 (1-100)	21.5 (2-100)	20.6 (3-80)
Earned wages as a musician (n, %) [e, h]	37 (86%)	32 (68%)	39 (57%)**

[a] Missing data for ≤ 10% of participants across each group.
[b] There was one case of missing data for the QAP males.
[c] Exposure to early music pedagogy that emphasized consistent tone-label mappings (fixed *do*).
[d] Fixed *do* instruments emphasize a fixed, categorical pitch, including the piano, organ, or electric keyboard. Movable *do* instruments included strings, woodwind, brass, or voice.
[e] There were two cases of missing data for the QAP males.
[f] All participants were able to read music (treble clef) with the exception of five RP musicians.
[g] This was based on each participant's estimate of the average hours spent practicing per week over the period for which the instrument was played.
[h] The majority of participants (68%) engaged in professional work as musicians, including music teaching and accompanying, performing in ensembles, orchestras or bands, solo performances (usually at social functions or in public music venues), busking, or composition of music pieces. Participants typically reported engaging in > 1 of these activities at the time of the study.
$^{***}p \leq .001$ $^{**}p \leq .01$ $^{*}p \leq .05$

most likely in AP compared to QAP and RP musicians was supported, $\chi^2(6) = 26.12$, $p < .001$. The intersection of factors, including a family history of AP, training onset in the sensitive period, and exposure to early training that emphasized a fixed *do*, is shown in Figure 2. AP musicians were most likely to report the presence of all three factors (16%), or two of three factors (47%). Only 34% reported one factor (training onset in the sensitive period), and only one AP musician (3%) reported that no factors were present. This AP individual had an atypical profile, having received private piano lessons based on a traditional movable *do* pedagogy for 12 months at the age of 10, with minimal further involvement in music. He reported rare early exposure to singing in the home, but had been exposed to a wide variety of classical and ethnic music since infancy and had access to a piano and a guitar in the family home. At the time of testing his main engagement with music was listening predominately to classical music on average four hours per week. This individual is consistent with a precategorical model of AP that does not require extensive music training (Ross et al., 2005). Apart from this individual, however, all others with high level AP had training onset in the sensitive period, with a family history of AP and early fixed *do* training only present when combined with training onset in the sensitive period (Figure 2).

In contrast to AP musicians, only a small percentage of RP musicians reported the presence of two factors (19%). The majority reported that either none of the factors was present (22%) or that only one factor was present (59%), typically onset of training in the sensitive period. Taken together, these findings indicate that training onset in the sensitive period is not sufficient for the expression of AP; rather, it is the interaction of factors that is significant. This is supported by the small percentage of RP musicians who showed either a family history of AP (5%) or early training that emphasized a fixed *do* during the sensitive period (11%), while no RP musician reported the presence of all three factors (Figure 2).

The pattern shown by the QAP musicians fell between the AP and RP groups. This was clearly demonstrated by the rank ordering of the number of factors present in each individual, with AP musicians having a greater mean rank for the presence of two or three factors (97.95) compared to the QAP (72.91) and RP (58.02) musicians, Kruskal-Wallis $\chi^2(2) = 24.07$, $p < .001$. Two QAP musicians reported the presence of all three factors. Of these, one scored close to the cut-off for membership of the AP group (86%), while the other showed variable pitch naming ability (60%) that increased to 76% when semitone errors were coded as correct. These two QAP musicians and the AP musician with the atypical profile

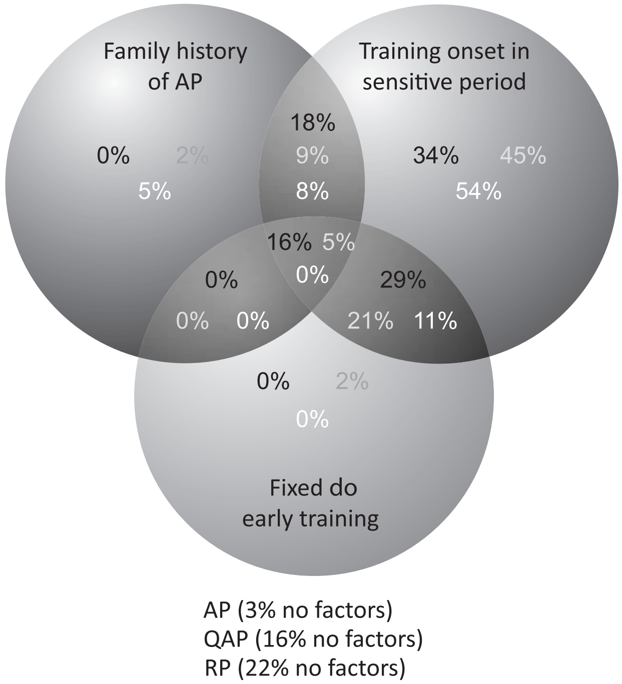

FIGURE 2. Venn diagram showing the percentage (%) of participants in the AP (black), QAP (gray), and RP (white) groups reporting the presence of a family history of AP, onset of music training in the sensitive period (3-7 years), and early exposure to music pedagogy emphasizing a fixed *do* (consistent tone-label mappings). A small percentage of participants reported none of these factors as shown outside the Venn diagram. Only participants with data available for all three variables were included ($N = 145$).

point to the contribution of other factors for variable expression of pitch naming ability.

CHARACTERIZING THE CURRENT MUSIC ENVIRONMENT OF AP MUSICIANS

Some striking differences emerged for markers of the current music environment that related to the music engagement and proficiency of the three groups. While all groups reported a similar level of general music engagement, as reflected by the amount of time spent listening to music each week (Table 2), a substantial difference emerged for the number of hours spent practicing per week, $F(2, 152) = 5.24$, $p = .006$, partial $\eta^2 = .07$. On average, AP musicians reported spending almost double the hours of practice compared to RP musicians (mean difference = -5.53, $p = .004$), whereas QAP musicians did not differ from either group ($p > .05$ for both comparisons). Similarly, AP participants were significantly more likely to earn wages as a musician, followed by QAP and RP musicians, $\chi^2(2) = 10.03$, $p = .007$ (Table 2), with musicians who earned wages undertaking significantly more hours practice per week ($M = 12.64 \pm 9.56$) than those who did not ($M = 7.54 \pm 6.26$), $t(132.51) = -3.94$, $p < .001$ (equal variances not assumed).

Combined with this, AP musicians were significantly more likely to report a fixed *do* instrument as the main instrument on which they currently performed and practiced, whereas RP musicians were more likely to name a moveable *do* instrument, $\chi^2(2) = 14.42$, $p = .001$ (Table 2). The mean number of years spent training on this principal instrument also differed, $F(2, 146) = 26.87$, $p < .001$, partial $\eta^2 = .27$, with RP musicians having spent less time than both AP (mean difference = -6.70, $p < .001$), and QAP musicians (mean difference = -4.54, $p < .001$). A related finding was observed for formal instruction in the theoretical aspects of music, $F(2, 152) = 5.45$, $p = .005$, partial $\eta^2 = .07$, which typically accompanies practical training in a graduated way. Again RP musicians had significantly less theoretical training than both the AP (mean difference = -2.12, $p < .05$), and QAP musicians (mean difference = -2.36, $p = .011$). These latter two findings may partly reflect the earlier age of onset of training of the AP and QAP groups, as this showed significant correlations both with years spent training on the principal instrument, and in music theory ($p < .01$ for both correlations).

Finally, there was no significant difference between the proportion of individuals who earned wages as a musician either playing a fixed (54%) or movable *do* (46%) instrument, $\chi^2(1) = 2.12$ $p = .146$. This suggests that while commencing on a fixed *do* instrument was most common (Table 2), changing to a movable *do* instrument did not preclude the significant amount of practice needed to achieve high levels of performance required for professional musicianship. In other words, becoming a professional musician did not appear to be a reason to keep playing the same instrument since childhood.

PREDICTING VARIABILITY IN PITCH NAMING ABILITY: THE PAST VERSUS PRESENT ENVIRONMENT

Given that the onset of music training in the sensitive period showed significant correlations with years spent training on the principal instrument and in music theory, these latter two variables were excluded from the MDFA to avoid multicollinearity. Supporting this, the pooled within-groups correlation matrix of the MDFA showed minimal correlations between the predictor variables (all $r < .17$), and assumption testing for homogeneity of covariance showed the log determinants of the group covariance matrices to be similar. Tests of equality of group means showed that expression of AP, QAP, or RP was most predicted by: exposure to a fixed versus movable *do* pedagogy in childhood (early training fixed *do*), followed by the principal instrument (at the time of testing) having a fixed or movable *do* (main instrument fixed *do*), training onset in the sensitive period, hours spent practicing per week, and a family history of AP (see Table 3). Together, the discriminating power of these variables was significant, Wilk's Lambda = .72, $\chi^2(10) = 44.34$, $p < .001$, and classified 59% of cases correctly (AP group = 63%, QAP group = 16%, RP group = 87%). Inspection of the eigenvalues revealed that of the two discriminant functions computed, the first accounted for 98.1% of the variance in group membership.

To investigate the unique contribution of each predictor, the standardized canonical coefficients were inspected. This revealed that early training fixed *do* and main instrument fixed *do* showed equal and significant contributions (0.54) to the first discriminant function, followed by hours spent practicing per week (0.47). A family history of AP and training onset in the critical period made more significant contributions to the second discriminant function (0.74 and 0.57 respectively). To further interpret the standardized canonical coefficients we assessed the structure matrix (see Table 4). This indicated that the first discriminant function principally reflected an "environmental factor" of exposure to a fixed *do*, both in early training and current regular performance of a fixed *do* instrument. In contrast, the second discriminant function was more suggestive of a "genetic factor," including the predisposition to develop AP based on family history, with the skill expressed in the context of training onset during the sensitive period. Interestingly, training onset during the sensitive period showed similar loadings on both discriminant functions, pointing to the pivotal role of this predictor in the expression of AP ability. Inspection of the territorial map indicated that the genetic factor principally differentiated the AP from the RP group, whereas the environmental factor differentiated between the RP and QAP, and QAP and AP groups.

TABLE 3. Tests of Equality of Group Means From the Multiple Discriminant Function Analysis (N = 142)

Predictor	Wilk's Lambda	*F*	df1	df2	*p*
Early training fixed *do* [a]	.89	8.67	2	139	< .001
Main instrument fixed *do* [b]	.91	6.79	2	139	.002
Training in sensitive period	.93	5.17	2	139	.007
Hours practice per week	.94	4.77	2	139	.01
Family history of AP	.95	3.63	2	139	< .05

Note: All cases with at least one missing discriminating variable (predictor) were removed from the analysis. df = degrees of freedom.
[a] Exposure to early music pedagogy that emphasized consistent tone-label mappings (fixed *do*).
[b] Fixed *do* instruments emphasize a fixed, categorical pitch, including the piano, organ, or electric keyboard. Movable *do* instruments included strings, woodwind, brass, or voice.

Discussion

The contribution of this study is twofold. First, our findings confirm the relevance of factors identified in previous research as significant to the expression of AP, including a family history of AP, training onset during a sensitive period, and exposure to early training that emphasizes a fixed *do* (consistent tone-label mappings). We then delineated the relative contribution of these factors to the expression of AP, and showed that no factor by itself is necessary or sufficient for the expression of AP. Rather, it is the co-occurrence of factors that is most salient, with AP musicians more often reporting a combination of two or three factors, whereas no RP musicians reported all three, and QAP musicians fell in between. Second, we have identified a new and equally important factor that contributes to the expression of AP, namely ongoing exposure to a fixed *do* instrument that is regularly played by the musician and presumably serves to reinforce the skill.

A similar contribution of past and present environmental influences to the expression of AP is a novel finding that is consistent with recent models of auditory processing that involve plasticity of auditory neural response fields in response to training (Fritz, Elhilali, & Shamma, 2005; Suga & Ma, 2003; Weinberger, 2003). Corticofugal plasticity provides a mechanism for long-term representations of sounds to influence early auditory perceptual processing. In particular, McLachlan and Wilson (2010) have proposed that long-term memory templates of sounds are used to integrate and stream subcortical feature processing, and associate this information with the activated template in auditory short-term memory. In this way, activation of a particular long-term memory template could modulate response fields in brain structures that innervate the primary auditory cortex. Auditory templates may also interact with patterns of auditory features that are encoded in the cortex over many seconds in auditory short-term memory through cortico-cortical connections. This mechanism would allow verbal labeling of a known melody or music structure, and would facilitate streaming of incoming acoustic patterns (Bregman, 1990).

In musicians with AP, an identifier (typically but not exclusively a verbal label) is associated with fine pitch information, which requires at least 10 waveform cycles

TABLE 4. Structure Matrix of the Multiple Discriminant Function Analysis (N = 142)

Predictor	"Environmental factor" (Discriminant function 1)	"Genetic factor" (Discriminant function 2)
Early training fixed *do* [a]	.58	−.28
Main instrument fixed *do* [b]	.51	−.15
Training in sensitive period	.44	.43
Hours practice per week	.43	−.22
Family history of AP	.36	.72

Note: All cases with at least one missing discriminating variable (predictor) were removed from the analysis. Positive values reflect the presence of the variable and its loading on the factor.

[a] Exposure to early music pedagogy that emphasized consistent tone-label mappings (fixed *do*).

[b] Fixed *do* instruments emphasize a fixed, categorical pitch, including the piano, organ, or electric keyboard. Movable *do* instruments included strings, woodwind, brass, or voice.

to compute (Hsieh & Saberi, 2007; Moore, 1973). This means that verbally labeled pitch templates in long-term memory could interact with afferent driven cortical representations of refined pitch information to facilitate pitch identification presumably via activation of the ventral auditory pathway (Griffiths & Warren, 2002; Lomber & Malhotra, 2008; Rauschecker & Tian, 2000). Combined with the role of the current environment, this suggests that in order to develop AP, individuals may first need to be exposed to consistent tone-label mappings early in life. This allows long-term reorganization of auditory cortex for the formation of pitch identification templates that likely occur via mechanisms of associative learning (Bermudez & Zatorre, 2005; Bregman, 1990; Griffiths & Warren, 2002; Hsieh & Saberi, 2007; Lomber & Malhotra, 2008; McLachlan & Wilson, 2010; Moore, 1973; Rauschecker & Tian, 2000; Suga, Gao, Ma, Sakai & Chowdhury, 2001; Weinberger, 2003). Once present, these templates may be maintained by ongoing exposure to consistent tone-label mappings through regular performance of a fixed *do* instrument. Together, these factors can then predict high-level expression of AP skill in musicians.

This model provides a possible explanation for intriguing reports that AP templates may change or become destabilized when attempting to name mistuned stimuli, which is distinct from changed pitch representations associated with aging of the basilar membrane (Ward, 1999). It is also consistent with the small number of AP musicians in our study whose principal instrument had changed from a fixed to a movable *do* (9%), and who spontaneously commented on the deleterious effects this had on their accuracy and speed of pitch naming performance. For example, one musician suggested that after moving from the piano to the B flat trumpet her pitch templates had "shifted" to match this, and that she now had to "transpose back" to C Major, greatly slowing her task performance. In this study, use of an ecologically common piano-like timbre established a fixed *do* context and allowed such effects to be elicited.

Our choice of stimuli was based on previous detailed investigations of the effects of timbre on pitch naming accuracy that clearly demonstrate that performance accuracy is dependent on both timbre and pitch height (Athos et al., 2007; Miyazaki, 1989; Takeuchi & Hulse, 1993). For example, Miyazaki (1989) found that accuracy is typically greatest for piano tones (> 90%), least for pure tones (~75%), and intermediate (~80%) for complex tones (synthesized piano-like tones, such as ours). Furthermore, accuracy is greatest for piano and complex tones in lower to middle pitch registers (C2-C5), whereas it is greater for pure tones (with superior performance to complex tones) above C5.

In the present study, we were principally interested in examining the effects of the current and past environment on pitch naming accuracy. In order to maximize our ability to test the differential effects of these factors, we chose a synthesized timbre within the range of C2-C5 that was highly familiar (piano sound), and to which all groups had been similarly exposed and trained on as their first instrument in childhood (first instrument fixed *do*). By keeping this early exposure relatively constant, we could then examine the differential contribution of being taught consistent tone-label mappings in early childhood (early training fixed *do*) and ongoing exposure to such mappings in adulthood (main instrument fixed *do*). Novel to this study is the finding that the majority of AP musicians still choose to play a fixed *do* instrument (namely the keyboard), that likely serves to reinforce rather than destabilize their long-term AP templates, thereby highlighting the relevance of ongoing "fixed *do*" exposure in adulthood for high level AP. An obvious next question is whether the current environment exerts such effects on the pitch naming of pure tones or multiharmonic synthetic stimuli that may be less relevant in a musician's daily life (noninstrument timbres). Such research would shed light on the specificity of current environmental influences to the expression of AP, including differential effects that may occur for musicians with different forms of AP (Bermudez & Zatorre, 2009).

In the MDFA of this study, membership of the QAP group was the least well predicted, suggesting that other factors likely account for variability within this group. Further subgroups likely exist within the QAP classification; for example, templates for white as opposed to back piano tones (pitch chroma subgroups) or tones with particular spectral characteristics (timbral subgroups; Miyazaki, 1990; Takeuchi & Hulse, 1993; Wilson et al., 2009). It is conceivable that in combination with a limited number of AP templates, QAP that is more stimulus bound could be supported by normal sound recognition mechanisms that use spectral pattern matching to estimate pitch height (McLachlan & Wilson, 2010). In their model of auditory processing, McLachlan and Wilson (2010) proposed that individuals with AP extract fine pitch information from high level cortical representations that integrate spectral and waveform information. In contrast, QAP individuals may rely more strongly on spectral (timbral) information that is available from sound onset via the pattern of auditory nerve excitation. This is consistent with the similar ability of AP and RP participants to recall stimulus timbre reported by Ross et al. (2005), and the finding that different forms of AP likely have different neurobiological substrates (Wilson et al., 2009). The territorial map of the MDFA indicated that the genetic factor broadly predicted expression of AP versus RP, but did not add significantly to the overall analysis for predicting membership of the three groups. Rather, this was done by the environmental factor, pointing to the likelihood that additional environmental variables will allow a more fine-grained differentiation of QAP templates. Thus, while the AP-1 phenotype has played an important role in initial genetic analyses (Baharloo et al., 1998; Baharloo et al., 2000), the challenge for future research is to provide a more complete characterization of AP phenotypes present within the broader population that takes these "more or less abstracted" pitch templates into account.

Finally, of all the factors contributing to the expression of AP, our study confirms the repeated finding of previous research that training onset during a sensitive developmental period is central for the expression of AP in the majority of individuals (Levitin & Zatorre, 2003). We showed that onset of training during this period was absent in more than double the proportion of RP compared to AP and QAP musicians. We also showed that the combination of factors contributing to the expression of AP always intersected with training onset during the sensitive period. In the MDFA, training onset during the sensitive period showed similar loadings on the environmental and genetic factors. This suggests that onset of training during the sensitive period may provide a pervasive or broad developmental context for the expression of AP in which other specific factors interact, such as past or current exposure to consistent tone-label mappings, or the presence of a biological marker for AP. Research by Schlaug and colleagues has suggested that structural asymmetry of the planum temporale, or local hyperconnectivity of the temporal lobe, although not specific to AP, may represent biological markers that are genetically encoded and facilitate the acquisition of AP in the presence of other environmental factors (Keenan, Thangaraj, Halpern, & Schlaug, 2001; Loui, Li, Hohmann, & Schlaug, 2011; Schlaug, Jäncke, Huang, & Steinmetz, 1995). In other words, these findings are consistent with a model of optimal timing for the expression of AP phenotypes.

Conclusion

Our findings point to the need for a shift in emphasis in the research field, moving away from debates about the necessary or sufficient nature of any given variable, toward a more comprehensive account of the relative contribution and interactions between variables that lead to the expression of AP skill. This shift will promote greater attention to a range of environmental factors, including the role of the current environment in the maintenance of AP templates. Such an approach promises greater understanding of the complex mechanisms underpinning the expression of different forms or phenotypes of AP, and may broaden our understanding of how genetic, maturational, and experiential factors interact in cognitive development.

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References

ATHOS, E. A., LEVINSON, B., KISTLER, A., ZEMANSKY, J., BOSTROM, A., FREIMER, N., & GITSHIER, J. (2007). Dichotomy and perceptual distortions in absolute pitch ability. *Proceedings of the National Academy of Science USA, 104,* 14795-14800.

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

BACHEM, A. (1940). The genesis of absolute pitch. *Journal of the Acoustical Society of America, 11,* 434-439.

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

BAHARLOO, S., JOHNSTON, P. A., SERVICE, S. K., GITSCHIER, J., & FREIMER, N. B. (1998). Absolute pitch: An approach for identification of genetic and nongenetic components. *American Journal of Human Genetics, 62,* 224-231.

BAHARLOO, S., SERVICE, S. K., RISCH, N., GITSCHIER, J., & FREIMER, N. B. (2000). Familial aggregation of absolute pitch. *American Journal of Human Genetics, 67,* 755-758.

BERMUDEZ, P., & ZATORRE, R. J. (2005). Conditional associative memory for musical stimuli in nonmusicians: Implications for absolute pitch. *Journal of Neuroscience, 25,* 7718-7723.

BERMUDEZ, P., & ZATORRE, R. J. (2009). A distribution of absolute pitch ability as revealed by computerized testing. *Music Perception,* 27, 89-101.

BREGMAN, A. S. (1990). *Auditory scene analysis: The perceptual organization of sound*. Cambridge, MA: MIT press.

BROWN, W. A., SACHS, H., CAMMUSO, K., & FOLSTEIN, S. E. (2002). Early music training and absolute pitch. *Music Perception, 19*, 595-597.

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

DE CHEVEIGNÉ, A. (2005). Pitch perception models. In C. J. Plack, A. J. Oxenham, R. R. Fay, & A. N. Popper (Eds), *Pitch: Neural coding and perception* (pp. 169-233). New York: Springer.

DEUTSCH, D. (2002). The puzzle of absolute pitch. *Current Directions in Psychological Science, 11*, 200-204.

DEUTSCH, D., DOOLEY, K., HENTHORN, T., & HEAD, B. (2009). Absolute pitch among students in an American music conservatory: Association with tone language fluency. *Journal of the Acoustical Society of America*, *125*, 2398-2403.

FRITZ, J. B., ELHILALI, M., & SHAMMA, S. A. (2005). Active listening: Task-dependent plasticity of spectrotemporal receptive fields in primary auditory cortex. *Hearing Research, 206,* 159–176.

GREGERSEN, P. K., KOWALSKY, E., KOHN, N., & MARVIN, E. W. (1999). Absolute pitch: Prevalence, ethnic variation, and estimation of the genetic component. *American Journal of Human Genetics, 65*, 911-913.

GREGERSEN, P., KOWALSKY, E., KOHN, N., & MARVIN, E. W. (2000). Early childhood music education and predisposition to absolute pitch: Teasing apart genes and environment. *American Journal of Medical Genetics A, 98*, 280-282.

GRIFFITHS, T. D., & WARREN, J. D. (2002). The planum temporale as a computational hub. *Trends in Neuroscience, 2*5, 348-353.

HALPERN, A. R. (1989). Memory for the absolute pitch of familiar songs. *Memory and Cognition, 17*, 572-581.

HSIEH, I-H., & SABERI, K. (2007). Temporal integration in absolute pitch identification of absolute pitch. *Hearing Research, 233*, 108-116.

KEENAN, J. P., THANGARAJ, V., HALPERN, A. R., & SCHLAUG, G. (2001). Absolute pitch and planum temporale. *NeuroImage, 14*, 1402-1408.

LEVITIN D. J. (1994). Absolute memory for musical pitch: Evidence from the production of learned melodies. *Perception and Psychophysics, 56*, 414-423.

LEVITIN, D. J., & ROGERS, S. E. (2005), Absolute pitch: Perception, coding, and controversies. *Trends in Cognitive Science, 9,* 26-33.

LEVITIN, D. J., & ZATORRE, R. J. (2003). On the nature of early music training and absolute pitch: A reply to Brown, Sachs, Cammuso, and Folstein. *Music Perception, 21,* 105-110.

LOMBER, S. G., & MALHOTRA, S. (2008). Double dissociation of "what" and "where" processing in auditory cortex. *Nature Neuroscience, 11,* 609-616.

LOUI, P., LI, H. C., HOHMANN, A., & SCHLAUG, G. (2011). Enhanced cortical connectivity in absolute pitch musicians: A model for local hyperconnectivity. *Journal of Cognitive Neuroscience, 23,* 1015-1026.

MCLACHLAN, N. M., & WILSON, S. J. (2010). The central role of recognition in auditory perception: A neurobiological model. *Psychological Review, 117,* 175-196.

MIYAZAKI, K. (1989). Absolute pitch identification: Effects of timbre and pitch region. *Music Perception, 7,* 1-14.

MIYAZAKI, K. (1990). The speed of musical pitch identification by absolute pitch possessors. *Music Perception, 8,* 177-188.

MOORE, B. C. J. (1973). Frequency difference limens for short duration tones. *Journal of the Acoustical Society of America*, *54*, 610-619.

PROFITA, J., & BIDDER, G. T. (1988). Perfect pitch. *American Journal of Medical Genetics, 29,* 763-771.

RAUSCHECKER, J. P., & TIAN, B. (2000). Mechanisms and streams for processing "what" and "where" in the auditory cortex. *Proceedings of the National Academy of Science USA, 97,* 11800-11806.

ROSS, D. A., GORE, J. C., & MARKS, L. E. (2005). Absolute pitch: Music and beyond. *Epilepsy and Behavior, 7*, 578-601.

SAFFRAN, J. R., & GRIEPENTROG, G. J. (2001). Absolute pitch in infant auditory learning: Evidence for developmental reorganization. *Developmental Psychology, 37,* 74-85.

SUGA, N., & MA, X. (2003). Multiparametric corticofugal modulation and plasticity in the auditory system. *Nature Reviews Neuroscience, 4,* 783-794.

SUGA, N., GAO, E., MA, X., SAKAI, M., & CHOWDHURY, S. A. (2001). Corticofugal system and processing of behaviourally relevant sounds: Perspective. *Acoustical Science and Technology, 22,* 85-91.

SCHLAUG, G., JÄNCKE, L., HUANG, Y., & STEINMETZ, H. (1995). In vivo evidence of structural brain asymmetry in musicians. *Science, 267*, 699-701.

TAKEUCHI, A. H., & HULSE, S. H. (1993). Absolute pitch. *Psychological Bulletin, 113,* 345-361.

TERHARDT, E., & WARD, W. D. (1982). Recognition of musical key: Exploratory study. *Journal of the Acoustical Society of America, 72,* 26-33.

VITOUCH, O. (2003). Absolutist models of absolute pitch are absolutely misleading. *Music Perception, 21,* 111-117.

WARD, W. D. (1999). Absolute pitch. In D. Deutsch (Ed.), *The psychology of music* (2nd ed., pp. 265-298). San Diego, CA: Academic Press.

WEINBERGER, N. M. (2003). The nucleus basalis and memory codes: Auditory cortical plasticity and the induction of specific, associative behavioral memory. *Neurobiology of Learning and Memory, 80,* 268-284.

WILSON, S. J., LUSHER, D., WAN, C. Y., DUDGEON, P., & REUTENS, D. C. (2009). The neurocognitive components of pitch processing: Insights from absolute pitch. *Cerebral Cortex 19,* 724-732.

WILSON, S. J., PRESSING, J., WALES, R. J., & PATTISON, P. (1999). Cognitive models of music psychology and the lateralisation of musical function within the brain. *Australian Journal of Psychology, 51,* 125-139.

ZATORRE, R. J. (2003). Absolute pitch: A model for understanding the influence of genes and development on neural and cognitive function. *Nature Neuroscience, 6,* 692-695.

ZATORRE, R., & BECKETT, C. (1989). Multiple coding strategies in the retention of musical tones by possessors of absolute pitch. *Memory and Cognition, 17,* 582-589.