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Absolute pitch in Costa Rica: Distribution of pitch identification ability and implications for its genetic basis

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Absolute pitch is the unusual ability to recognize a pitch without an external reference. The current view is that both environmental and genetic factors are involved in the acquisition of the trait. In the present study, 127 adult musicians were subjected to a musical tone identification test. Subjects were university music students and volunteers who responded to a newspaper article. The test consisted of the identification of 40 piano and 40 pure tones. Subjects were classified in three categories according to their pitch naming ability: absolute pitch (AP), high accuracy of tone identification (HA), and non-absolute pitch (non-AP). Both the percentage of correct responses and the mean absolute deviation showed a statistically significant variation between categories. A very clear pattern of higher accuracy for white than for black key notes was observed for the HA and the non-AP groups. Meanwhile, the AP group had an almost perfect pitch naming accuracy for both kinds of tones. Each category presented a very different pattern of deviation around the correct response. The age at the beginning of musical training did not differ between categories. The distribution of pitch identification ability in this study suggests a complex inheritance of the trait.
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I. INTRODUCTION

Absolute pitch (AP), also known as perfect pitch, is the unusual ability to recognize a pitch without an external reference. This rare "musical superpower" has been a research subject for more than 100 years. Despite the interest generated by AP, it is agreed that its possession is not relevant for performance in most musical tasks.

There is presently no standard method for the behavioral determination of the presence of absolute pitch in an individual, and different studies have used different approaches. Self-report by participants has been used by several studies, and while some have found it to be reliable (Gregersen *et al.*, 1999; Keenan *et al.*, 2001) others have reported a high rate of false positives (Baharloo *et al.*, 2000). In studies where possession of AP has been corroborated, the most common tests have included listening to piano notes or sine waves (pure tones) and naming or writing the tone. The use of sine waves forces the subjects to identify tones based on their fundamental frequency, without clues from an instrument's timbre, for example (Takeuchi and Hulse, 1993). The number and duration of tones presented, octave range used, whether octave identification is requested of the participants, reaction time collection, degree of automation of the test, and performance criteria for the categorization of subjects have varied greatly from study to study (Miyazaki, 1988; Zatorre and Beckett, 1989; Takeuchi and Hulse, 1993; Baharloo *et al.*, 1998; Baharloo *et al.*, 2000; Gregersen *et al.*, 1999; Athos *et al.*, 2007; Bermudez and Zatorre, 2009; Oechslin *et al.*, 2009; Theusch *et al.*, 2009; Rakowski and Rogowski, 2011; Gregersen *et al.*, 2013).

The extent of the influence of genetic and environmental aspects in the development of absolute pitch has always been a controversial subject. There is evidence from previous studies to support the importance of both factors. In terms of environmental influence, the most cited observation is that early musical training (before 6 years of age) is necessary but not sufficient for the development of AP (Miyazaki, 1988; Baharloo *et al.*, 1998; Gregersen *et al.*, 2001). Additionally, AP has been reported to be more frequent in people who speak tonal languages (Deutsch, 2006; Deutsch *et al.*, 2006), or lost their sight at an early age (Hamilton, 2004).

As evidence in favor of the genetic component of AP, different studies have found familial aggregation for this phenotype (Baharloo *et al.*, 1998; Gregersen *et al.*, 1999; Baharloo *et al.*, 2000; Zatorre, 2003; Theusch *et al.*, 2009). Additionally, a higher concordance rate in monozygotic than dizygotic twins has been reported (Theusch and Gitschier, 2011). Some unusual families present with several individuals with AP and a seemingly Mendelian mode of inheritance. In these cases, an autosomal dominant pattern of inheritance with incomplete penetrance has been proposed as the most likely (Baharloo *et al.*, 1998). However, a study where segregation analysis was performed failed to confirm Mendelian inheritance for the trait (Theusch and Gitschier, 2011). A linkage analysis performed with 73 relative pairs with absolute pitch found linkage to the 8q24.21 region, but the presence of several independent linkage peaks suggests locus heterogeneity (Theusch *et al.*, 2009). In another study, a combined linkage analysis of multiplex families with AP

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and multiplex families with synesthesia (based on evidence of association of both traits) resulted in a significant linkage to the 6q region (Gregersen *et al.*, 2013).

Additionally, several studies have provided evidence in favor of a biological basis of the trait. Structural modifications, such as an exaggerated leftward asymmetry of the planum temporale (Schlaug, 1995; Keenan *et al.*, 2001) and an increased structural connectivity between the superior temporal gyrus and the middle temporal gyrus (Loui *et al.*, 2011) have been reported in AP possessors when compared to controls. At a functional level, a stronger activation of the left superior temporal sulcus during a pitch memory experiment (Schulze *et al.*, 2009), and of the left superior temporal gyrus when listening to music (Loui *et al.*, 2012) have been reported for AP subjects than for individuals without AP.

Some authors have proposed that AP is a distinct perceptual trait, with a clear bimodal distribution (with or without AP) (Profita and Bidder, 1988; Athos *et al.*, 2007). An opposing view considers that AP ability shows instead a continuous distribution (Levitin, 1999; Vitouch, 2003; Levitin and Rogers, 2005; Bermudez and Zatorre, 2009).

The aim of the present study is to describe and analyze the distribution of tone identification ability in a sample of Costa Rican persons with musical training. Based on the distribution of the trait in the population, we hypothesize about the possible roles of genetic factors in the acquisition of absolute pitch.

II. METHODS

The project was approved by the Research Ethics Committee of the University of Costa Rica. Every participant gave informed consent.

A total 127 individuals, 73 men and 54 women, with musical training took part in the investigation. Subjects were recruited using a mixed strategy, which included visiting lessons at the Music School of the University of Costa Rica, visiting private music academies, and recruiting volunteers who responded to a newspaper article.

Participants completed a similar survey to that used in previous studies (Baharloo *et al.*, 1998). Subjects answered questions about the age at beginning of music lessons, the duration of the musical training and the instruments they play. Additionally, there were questions about the speed and accuracy of their pitch identification, the ability to identify tones generated by different instruments or non-musical tones, and the ability to generate a requested tone vocally. All of the participants are native Spanish speakers (which is not a tonal language); and none of them speak a tonal language.

For the tone identification test, a modified version of the test used by Baharloo and collaborators (1998) was used. As in the previous study, two types of tones were used: pure sine-wave tones and piano tones. The software used for tone generation was AVID PRO TOOLS version 7. The audio interface used was an AVID Digi 003 Rack. For sine wave generation, the virtual instrument plugin Xpand (Air) was used, with the Mono Sine sample (Basics 027). Sines were generated from C2 to B6. For piano tones, the virtual instrument plugin Mini Grand (Air) was used, with the "Real Piano" model patch. Studio Room reverb was used at 16% mix, and tuning scale was set at equal (not "stretched"). Notes were generated from C2 to B6. Duration of tones in both sine wave and piano tones was set to 1 s. Both sine waves and piano tones were saved as individual waveform audio files (.WAV) at 44 100 Hz sampling rate and 16 bits resolution, equivalent to CD-quality.

Two tests were administered to each subject. The first included 40 piano tones and the second 40 pure tones. Each tone was played for one second. There was a 3 s interval between tones, in which the subject wrote down the name of the tone on a sheet of paper. A small break (less than 30 s) was given between the piano and pure tone tests. Tones were played in random order (without repetition). Subjects listened to the tones through headphones. Subjects were not allowed any practice runs, and feedback was given only after testing was completed.

Percent correct and mean absolute deviation (MAD) (Bermudez and Zatorre, 2009) were used as measures of accuracy. The percentage of correctly identified tones for each subject was calculated separately for natural tones and flat/sharp tones. MAD was calculated by recording the absolute value of the semitone deviation from the correct answer (i.e., for a C# identified as a C, a subject received a MAD of 1) and calculating the mean of these values across all tones for a given participant. A random response pattern yields a MAD of 3, while perfect identification yields a MAD of 0.

Subjects were grouped in three categories: absolute pitch (AP), high accuracy of tone identification (HA), and non-absolute pitch (non-AP). Individuals with a pitch naming accuracy higher than 90% and a MAD lower than 0.1 were categorized as AP. For assignment of individuals to the other two categories the SEGREG (2014) software was used. This software selects the most statistically significant linear model that consists of up to two linear segments. When a two-segment model is the most appropriate one, the program computes the bend point and estimates its standard error. The bend point was used to determine the breakpoint between the HA and the non-AP groups. The bend point obtained was 54.73% correct identification +/−SE 1.13 (significant with a 90% confidence block around the bend point). Individuals with scores below the bend point were classified as non-AP and individuals with scores above the bend point were classified as HA. Based on this classification, 17 individuals were included in the AP group, 22 in the HA group, and 88 in the non-AP group.

One way analysis of variance (ANOVA) was used for comparison of the percentage of accurate tone identification, mean absolute deviation, and the age at beginning of musical training between the AP, HA, and non-AP groups. For statistical analysis of the proportion of correct tones, the arcsine of the square root of the proportion of correct tones was used (the percentage of correct tones was then used for graphical representation of the data). A two-way ANOVA was used to compare the accuracy of identification for natural and flat/sharp tones in the three groups. A chi-square test was used for the comparison of gender, intensity of training and age distribution between categories of pitch naming ability.

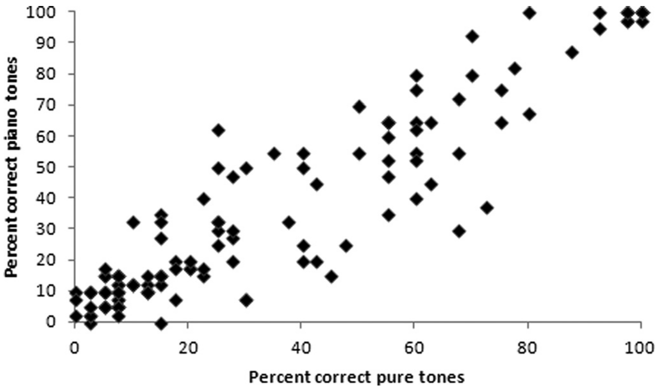

FIG. 1. Scatter plot produced on the basis of pure tone and piano tone scores in the complete sample of participants. In general, a positive correlation between both kinds of scores can be seen, but the concordance varies between individuals.

III. RESULTS

As shown in previous studies, there is a general concordance in the individual accuracy of pitch identification for piano and pure tones (Fig. 1). The mean difference in the percentage of correctly identified tones between piano and pure tones is 1.24% ± 1.04 [standard error (SE)]. However, some individuals showed a difference in accuracy according to the kind of tone, as can be seen for the subject who identified 68% of the pure tones but only 30% of the piano tones correctly.

For the purpose of later analysis, participants were classified in three groups (as described in Sec. II) according to their pitch naming ability: absolute pitch (AP), high accuracy of tone identification (HA), and non-absolute pitch (non-AP) (Fig. 2). Individuals in the HA category show high pitch naming ability, but do not reach the threshold set for the AP group. A general description of the number of subjects in each group and the instruments they play is presented in Table I. While the distribution of men and women does not differ significantly between categories ($X2 = 5.3$, d.f. $= 2$, $p = 0.07$), the near significant difference is mainly due to the higher number of men in the AP group (Table I). The distribution of the subjects by the intensity of musical training is also shown in Table I. Subjects with intensive musical training are either current or former members of a symphony orchestra, or piano students at music academies for concert-level pianists (2–4 h of training per day). The intensity of training was found to vary between groups ($X2 = 30.39$, d.f. $= 2$, $p = 2.5 \times 10^{-7}$), with the HA group presenting the highest proportion of intensive training (82%). Over 70% of the subjects in the HA group are pianists.

The means for the percentage of correct identification of tones and the mean absolute deviation are shown for the AP, HA, and non-AP groups in Table II. Correct identification of tones varies between groups ($F = 319.4$, d.f. $= 126$, $p = 1.22 \times 10^{-49}$). The accuracy of the identification is highest in the AP group, followed by the HA group, with the non-AP subjects being the least accurate (Tukey, $p < 0.001$ for all pairwise comparisons). The mean absolute deviation from the correct tone (MAD) also shows variation between groups ($F = 100.4$. d.f. $= 126$, $p = 1.17 \times 10^{-26}$). In concordance with the expected inverse pattern between tone identification accuracy and MAD, the lowest MAD is found in the AP group, followed by the HA group, and then the non-AP group (Tukey, $p < 0.05$ for all pairwise comparisons).

A two way ANOVA which compared the accuracy of tone identification for natural versus sharp/flat tones in the three groups (AP, HA, non-AP) yielded a significant interaction ($F = 13.7$, d.f. $= 2$, $p = 1.27 \times 10^{-6}$). The interaction is due to the different response in tone identification found in the AP group (Fig. 3). Both the HA group and the non-AP subjects show a clear pattern, with a significantly higher accuracy of identification of natural tones than of flat/sharp tones. In the AP group, however, accuracy is close to 100%, irrespective of the kind of tone that was presented.

This pattern can be seen in more detail in Fig. 4, where the accuracy of the total responses of each group is shown for each tone. Once again, accuracy fluctuates according to pitch class in the HA and non-AP groups, but not in the AP group.

The pattern of semitone deviations from the correct response also varies between groups (Fig. 5). In the AP group the subjects identified the tone correctly almost every time (99%). In the HA group, the tone was correctly identified 69% of the time, and almost all incorrect responses were one semitone higher or lower than the correct tone. The pattern is very different in the non-AP subjects, where close to 23% of the responses were correct and for the rest there is a distribution among all possible semitone deviations.

The average age of beginning of musical training (in the form of music lessons) was not found to vary between the non-AP, HA, and AP groups ($F = 2.971$, d.f. $= 126$, $p = 0.06$) (AP: $M = 7.62 \pm$ SE 0.95, HA: $M = 6.05 \pm$ SE 0.78, non-AP: $M = 8.52 \pm$ SE 0.48). The distribution of the individuals in

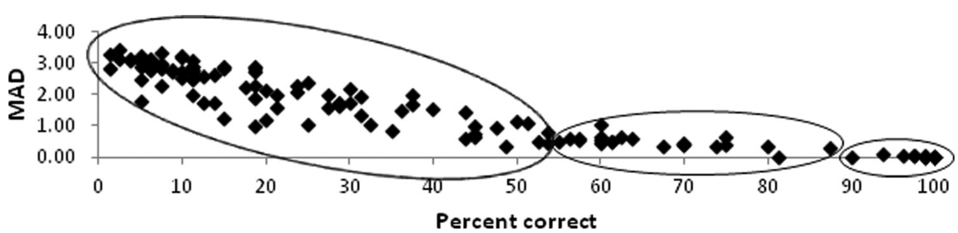

FIG. 2. Percent correct versus mean absolute deviation for pitch identification. The group on the left represents the non-AP individuals, with the lowest accuracy and highest deviation in pitch identification. The middle group represents the HA subjects, which presented intermediate values. Subjects were assigned to the non-AP and HA groups using the SEGREG software (the breakpoint is 54.73% correct identification). The AP group on the right has more than 90% accuracy and the mean absolute deviation is less than 0.1.

TABLE I. Description of participants in the AP, HA, and non-AP groups. The number of men, women and total number of subjects is shown for each group. The distribution of the first instrument played by the subjects, as well as the current instrument they play is also shown. The number of individuals with current intensive vs non intensive musical training is shown in the right column. Intensive training was defined as two to four hours of training every day.

		First instrument				Current instrument				
	Men:women (Total)	Piano	Guitar	Violin	Other	Piano	Guitar	Violin	Other	Intensive: non-intensive
AP	14:3 (17)	4	4	4	5	3	4	3	7	5:12
HA	13:9 (22)	16	2	1	3	15	1	2	4	18:4
Non-AP	46:42 (88)	32	16	8	32	34	12	9	33	18:70

the different categories of pitch identification by age at commencement of musical training does not show a significant variation between groups (X2 = 16.41, d.f. = 10, p = 0.09) (Fig. 6), even though a slight shift toward earlier ages of beginning of training can be seen for the AP and HA individuals.

IV. DISCUSSION

To the best of our knowledge, this is the first study on the subject of absolute pitch in Costa Rica. We were able to objectively test and characterize tone identification ability in 127 musically trained subjects. Based on the results, individuals were assigned to one of three groups of tone-naming ability. We hypothesize that the differences in performance between groups can give clues about the balance between genetic and environmental factors that favor the development of the trait.

It is important to note that comparison of different studies on absolute pitch is not easy. Although the definition of absolute pitch is clear, the accuracy in pitch identification required in order to consider a participant as AP possessor varies between studies (Miyazaki, 1988; Baharloo *et al.*, 1998; Gregersen *et al.*, 2001; Temperley and Marvin, 2008; Bermudez and Zatorre, 2009; Deutsch *et al.*, 2006; Dooley and Deutsch, 2010).

Studies of this kind, where participants volunteer for the test are inherently biased. In general, individuals who think they have AP volunteer, while those who know that they do not have it do not take part in the study. In this respect, the results from university music students were very valuable. With the collaboration of a professor at the music department, it was possible to test entire groups of students. None of them presented AP, and were therefore useful in establishing the accuracy of pitch identification in a general population of individuals with musical training.

We used a strict definition of AP; including individuals with more than 90% accuracy and a MAD of less than 0.1. AP subjects in this study present an extreme phenotype; eight out of the 17 AP individuals identified all 80 tones correctly. The HA group defined in the present study is very interesting and deserves a more detailed analysis. The 22 HA subjects correctly identified on average around two-thirds of the tones. This group shows a very low deviation from the correct tone; most incorrectly identified tones were off by only a semitone (Figs. 2 and 5). They represent a middle category between true AP and true non-AP possessors. The classification of pitch naming ability into three categories has also been used in other studies (Miyazaki, 1988; Temperley and Marvin, 2008; Dooley and Deutsch, 2010; Loui *et al.*, 2011; Loui *et al.*, 2012).

If it is assumed that the development of AP is determined by the interaction between genetic predisposition for the development of the trait and environmental factors, the HA category could possibly include individuals with intermediate to slightly elevated genetic predisposition and very intensive musical training. As evidence in favor of this hypothesis, 82% of the HA subjects versus only 42% of the AP subjects presented intensive training (Table I). Loui and collaborators (2011), who also used three categories of pitch naming accuracy, had also proposed the idea that pitch identification may depend strongly on training for the middle category.

Our results differ from previous studies, which found greater accuracy of identification for the white keys than for the black keys of the piano in AP musicians (Miyazaki, 1988; Bermudez and Zatorre, 2009). In the present study the greater accuracy for the white keys was evident in the HA and non-AP groups, but not in the AP group. One possible explanation is that the strict categorization criteria used in our study led to a very homogeneous and high-performing

TABLE II. Mean accuracy and deviation (± standard error) of tone identification in the AP, HA, and non-AP groups.

	Percent correct (±standard error)	MAD (±standard error)
AP	98.24 (±0.66)	0.01 (±0.01)
HA	66.5 (±1.93)	0.49 (±0.04)
Non-AP	20.07 (±1.58)	2.18 (±0.09)

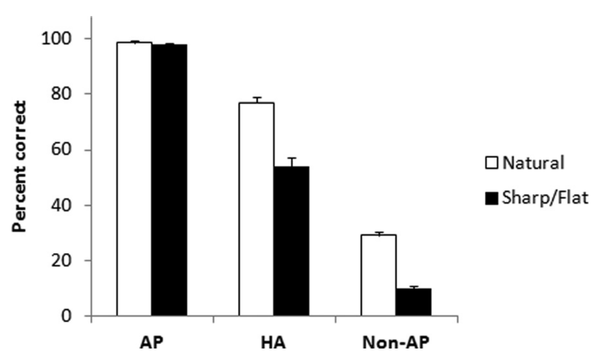

FIG. 3. Accuracy of identification for each pitch class by group (AP, HA, non-AP). Mean values (± standard error) of the percentage of correct pitch identification are presented. The natural tones are shown in white and the sharp/flat tones in black.

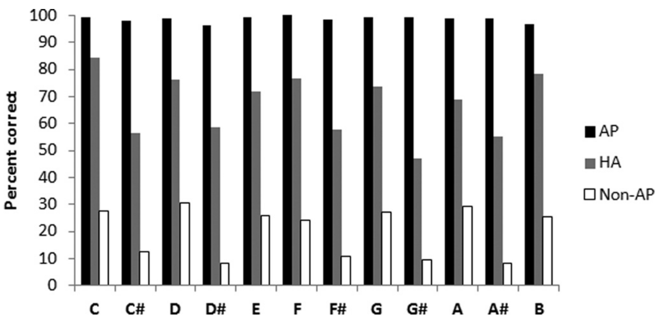

FIG. 4. Accuracy of total responses by tone and group. The percentage of correct pitch identification for all 12 tones is shown for the AP (black), HA (gray), and non-AP (white) groups.

AP group, with almost perfect identification of any kind of tone.

The distribution of semitone deviations from the correct response presents a very different pattern in the three categories of pitch naming ability (Fig. 5). As has been previously shown (Ross *et al.*, 2003; Bermudez and Zatorre, 2009), deviation from the correct response is mainly 0 for the AP group. For the HA group the distribution around the correct response is narrow (ranges mainly from -1 to $+1$ semitone deviations). Loui and collaborators (2011) found a pattern of semitone variations in the three categories they used that is remarkably similar to that in the present study. The middle category is clearly different from the strict AP category, in that the subjects make more semitone errors. If, as proposed by Zatorre (2003), the two requirements for the development of absolute pitch are very narrow fixed pitch categories and the association of these categories with verbal labels, the data could suggest that the HA group has a clear association of pitch categories with verbal labels, but their pitch categories are not narrow enough.

It is of interest that, as pointed out by Levitin and Rogers (2005), even in non-AP possessors pitch identification is not random. The non-AP group identified 20% of tones correctly, which is more than double the accuracy expected by chance alone (1 in 12 tones correctly identified, roughly 8%). It has been shown that even musically untrained individuals have some level of absolute pitch memory for familiar tones, such

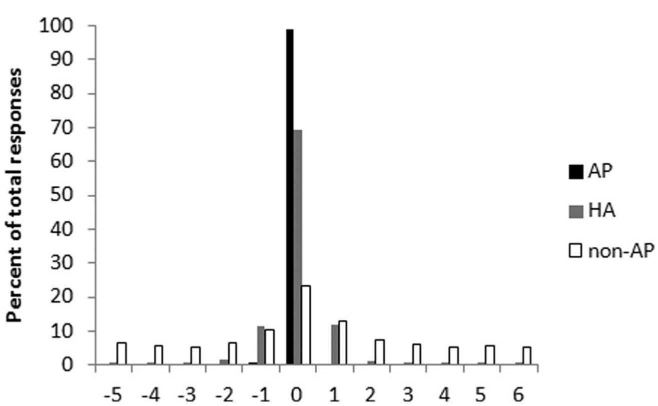

FIG. 5. Histogram of semitone deviations from the correct response for the AP (black), HA (gray), and non-AP (white) groups. AP subjects show an almost unimodal distribution, while the range of semitone deviations in the HA group is narrow. The non-AP group presents a much broader range of deviations, but the mode is centered on correct identification.

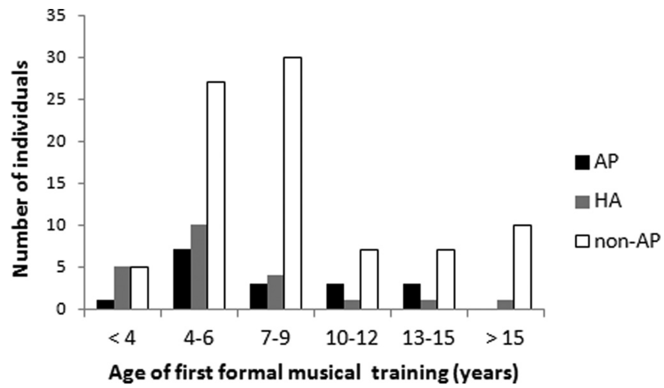

FIG. 6. Distribution of AP (black), HA (gray), and non-AP (white) individuals by age of first musical training. The age categories are defined in three-year intervals.

as popular songs or the telephone dial tone (Levitin, 1994; Smith and Schmuckler, 2008).

The average age at the beginning of musical training did not differ between AP and non-AP subjects (Fig. 6), challenging the assumption that early musical training is a requirement for the development of AP. Six out of the 17 subjects with AP began musical training after 10 years of age. One of them began playing the guitar when he was 14, and never had formal music lessons. Vitouch (2003) has proposed that assuming that "early musical training" is necessary for acquisition of the trait is too general. He argues that it is a special kind of musical training (tonal training of the "find the note kind") that leads to the development of absolute pitch in certain people. A possible hypothesis is that this special musical training is important for individuals with an intermediate genetic predisposition. In this scenario, in the presence of a strong genetic predisposition, musical training could start at more advanced ages and the subject would still develop AP.

Supporters of a bimodal distribution for AP ability have proposed that the trait could be governed by the influence of one or a few genes, modulated by early exposure to music (Profita and Bidder, 1988; Athos *et al.*, 2007). Even if the AP phenotype were dichotomous, this does not rule out the possibility that the trait presents complex inheritance. Under the liability threshold model, multiple genetic and environmental factors determine the liability (predisposition) of each individual for presenting a trait, and this liability shows a normal distribution in the population. All those whose liability exceeds a threshold exhibit the trait, resulting in a binary classification of the phenotype (Dudbridge, 2013).

Our results, however, do not show a dichotomous distribution and support the idea proposed by other researchers that pitch naming ability exists along a continuum (Levitin, 1999; Vitouch, 2003; Levitin and Rogers, 2005; Bermudez and Zatorre, 2009). As can be seen in Figs. 1 and 2, the subjects in the present study exhibit different levels of pitch naming ability and cannot be simply grouped as with or without AP. This continuous distribution of the trait is in accordance to what would be expected for a complex trait. In complex traits, the phenotype of an individual is determined by the action of several genes (that determine genetic predisposition) in interaction with the environment. Some of those genes may have a larger effect on the phenotype than others (McClellan and King, 2010). Most human traits present this kind of inheritance; phenotypes determined by one or a few genes are the exception, not the rule. In complex traits both nature and nurture play a crucial role, with the new field of epigenetics potentially acting as a link between the two. We argue that there is not enough evidence at present of Mendelian inheritance of absolute pitch, and that so far the information in the literature supports a multifactorial or complex inheritance.

Assuming a complex trait model, we propose as a hypothesis that the different groups for tone identification ability of the present study differ in the balance of genetic and environmental factors that make an individual susceptible to the development of absolute pitch. In the non-AP group, genetic and environmental predisposing factors are low. In the HA group, genetic predisposition is intermediate and the environmental predisposing factors are high (most likely in the form of very intensive training). In the AP group, genetic predisposition is very high, which means that environmental predisposing factors can be low or high (but not altogether absent, because knowledge of the notes is required) and the person will acquire the trait.

It is clear that the subjects who met our strict requirements for the absolute pitch category present an extreme phenotype. In the present study, subjects took the pitch identification test in the presence of the researcher. Their pitch naming ability is certainly impressive: there is immediate identification of the presented tones, there is no hesitation, and no attempt to use relative pitch. In informal interviews after the test, AP subjects consistently described that the name of the tone "pops into their heads" and they cannot explain how tone recognition is achieved. This observation supports the idea that AP subjects verbally label tones in an automatic manner (Schulze *et al.*, 2012). As was previously mentioned, several of the AP subjects in the present study started their musical training relatively late and never had intensive training. We propose that these individuals are born with a very high genetic predisposition for the development of the trait, and therefore a relatively short exposure to the tones and their names is sufficient for acquisition of absolute pitch. In the complex inheritance model, this very high genetic predisposition will be due to many genetic variants of small to medium effect in several (as of yet unknown) genes. This does not exclude the possibility that in a few of the cases the very high genetic predisposition is caused by one genetic variant of large effect.

The observed structural and functional modifications in the temporal lobe of AP subjects are likely to be related to the development of the trait (Schlaug, 1995; Keenan *et al.*, 2001; Schulze *et al.*, 2009; Loui *et al.*, 2011; Loui *et al.*, 2012). In particular, the hyperconnectivity of the temporal lobes and stronger activation of the left superior temporal sulcus have been proposed to be related to the superior categorization skills shown by AP subjects (Loui *et al.*, 2011; Schulze *et al.*, 2009). The presence of very narrow fixed pitch categories is one of two cognitive components proposed by Zatorre (2003) as required for the acquisition of AP. The other component is the association of these categories with verbal labels. In that regard, a study by Schulze and collaborators (2012) has suggested that that verbal labeling of tones is at least partly automatic in AP musicians. It has also been proposed that a large auditory memory span could favor the development of associations between pitches and their verbal labels early in life, therefore promoting the acquisition of AP (Deutsch and Dooley, 2013). Going back to considerations about the genetic basis of the trait, it is unlikely that the diverse structural and functional brain modifications that have been found in AP subjects, as well as the separate cognitive components of the trait could result from the action of a single gene.

If pitch naming ability is a truly complex trait, determined by the action of many genes of small-to-medium effect and environmental influence, there will be considerable difficulty in fully understanding its genetic basis. One possible strategy for future studies is to restrict genetic analyses to individuals with perfect tone identification (no mistakes in the test), in order to maximize the genetic predisposition of the analyzed subjects. Ideally, one or more large families with several individuals with perfect tone recognition could be used for linkage analysis, in the hope of identifying a genetic region that is linked to the trait.

As previously argued by Bermudez and Zatorre (2009), some of the differences in the results from different absolute pitch studies can be attributed to differences in how AP was defined, the testing methods, and the grouping of the subjects for analysis. Standardization of stimuli and administration parameters in the tests would certainly benefit future studies, by providing comparable results.

V. CONCLUSIONS

We identified three different levels of pitch naming ability in 127 subjects with musical training. Our evidence does not support the idea of absolute pitch as a binary trait, which can be described as either present or absent, but rather as a continuous trait. The existence of an intermediate category of subjects with a high ability for tone identification is apparent both in the efficiency of tone identification and in the deviation around the correct response. Our results support the growing evidence that absolute pitch constitutes an extreme phenotype in the continuous distribution of pitch naming ability in the population.

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