A nonmusical paradigm for identifying absolute pitch possessors

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The ability to identify and reproduce sounds of specific frequencies is remarkable and uncommon. The etiology and defining characteristics of this skill, absolute pitch (AP), have been very controversial. One theory suggests that AP requires a specific type of early musical training and that the ability to encode and remember tones depends on these learned musical associations. An alternate theory argues that AP may be strongly dependent on hereditary factors and relatively independent of musical experience. To date, it has been difficult to test these hypotheses because all previous paradigms for identifying AP have required subjects to employ knowledge of musical nomenclature. As such, these tests are insensitive to the possibility of discovering AP in either nonmusicians or musicians of non-Western training. Based on previous literature in pitch memory, a paradigm is presented that is intended to distinguish between AP possessors and nonpossessors independent of the subjects' musical experience. The efficacy of this method is then tested with 20 classically defined AP possessors and 22 nonpossessors. Data from these groups strongly support the validity of the paradigm. The use of a nonmusical paradigm to identify AP may facilitate research into many aspects of this phenomenon.
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I. INTRODUCTION

Most individuals perceive melodic sequences without being able to identify absolutely the notes involved. For example, most people could recognize Beethoven's Fifth Symphony but would not know that the first note is a ''G.'' This example illustrates that the perception of tonal sequences is generally dependent on the ability to recognize the relationships between notes, rather than on recognizing the exact frequency of each note. When further refined, this skill—the ability to identify or produce musical intervals accurately—is referred to as ''relative pitch'' (RP).

A small subset of the population is also capable of quickly and accurately labeling tonal stimuli on the basis of their fundamental frequencies (without the use of a reference tone). This skill is generally referred to as ''absolute pitch'' (AP), or, colloquially, as ''perfect pitch.'' This phenomenon has been of interest to musicians and scientists alike for many years, in large part because of the musical advantages it may endow. For example, it may be easier for AP possessors to transcribe or remember a piece of music because they can directly identify each of the notes that are played. Similarly, it may be easier for them to sight-sing difficult passages by producing each note individually rather than trying to tune challenging intervals. AP possessors may also be limited in several important ways. Strict adherence to the absolute frequencies of tones as found in the equal-tempered scale could hinder a possessor's ability to remain in tune with a choir that drifts flat or to maintain proper intonation on intervals that differ from equal temperament. There are also reports of AP musicians who find that their sense of pitch shifts as they grow older, possibly due to changes in the elasticity of the basilar membrane.[1,2]

A central point of controversy in the study of AP has been the relative roles of heredity and early musical experience. While a parsimonious approach might allow that both genetic and epigenetic factors are involved, few authors in the field have adopted such a moderate stance. Early models of AP suggested that ''true'' AP is a genetically determined trait[3,4] and several recent papers have provided convincing evidence that AP has a genetic component.[2,5–7] Other models of absolute pitch have argued that AP results from early learning experiences.[8–11] These models generally propose that early in life some individuals memorize the exact frequency of each note in the musical scale, either consciously or unconsciously, resulting in absolute pitch abilities. Indirect evidence in support of this theory is drawn from the

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[a)] Electronic mail: david.a.ross@yale.edu finding that all reported AP individuals possess extensive early musical training,[4,11] and that the degree of AP tends to correlate with years of musical training.[9] However, the data supporting this theory are problematic since AP testing methods have been biased towards identifying individuals who possess musical training. Specifically, most paradigms have employed a labeling technique in which subjects are played a series of musical tones and are asked to name the notes according to the Western musical scale. Performance on such a test is predicated on a basic level of musical expertise and is therefore insensitive to the possibility of discovering AP in either a nonmusician or a musician of non-Western training. As such, there is no convincing evidence that only musicians possess AP.[12]

The goal of the present study was to develop a paradigm that could distinguish between AP possessors and nonpossessors without requiring subjects to have knowledge of (or at least without requiring subjects to use) conventional musical nomenclature. The paradigm that we developed for this purpose resembles one used by Siegel,[13] in which she asked AP possessors and nonpossessors to make same/different judgments about a target stimulus following a series of interfering tones. We refined Siegel's design so as to present subjects a target stimulus followed either by a silent interstimulus interval (ISI) or one filled with interfering tones, after which the subjects were asked to reproduce the original tone by adjusting the knob of a sine function generator. We expected that both groups would perform this task with relative accuracy after a silent ISI. In contrast, a significant body of literature indicates that passive exposure to as few as four to seven interfering tones should be sufficient to destroy completely a non-AP subject's memory for the target[14–17] whereas AP subjects should remain accurate.[13,18,19] Thus, we expected that this paradigm would be able to distinguish accurately between AP and NAP individuals.

Importantly, this paradigm does not require subjects to make use of any musical knowledge or training: subjects are never asked to name musical notes nor are they asked to produce musical notes by name. As discussed by Siegel, we do not deny the possibility that a subject *could* apply categorical labels to the target stimuli in order to maintain representations of them. However, it is important to emphasize that this task focuses strictly on the ability of subjects to encode durable long-term representations of target stimuli. The extent to which this skill overlaps with the ability to name notes (and thus corresponds to classically defined ‘‘perfect pitch’’) will be a point of great interest.

II. EXPERIMENT 1

A. Method

1. Participants

At this time, because we were strictly interested in testing the validity of our paradigm, only experienced musicians were included (i.e., individuals who could easily be classified as AP possessors or nonpossessors using standard methods). Nine musicians participated in the original version of this experiment (3 AP, 6 NAP) and 33 subjects (17 AP, 16 NAP) took part in an abbreviated version. The 20 AP possessors (10 male) had an average age of 23.1±7.6 and an average of 17.2±8.0 years of performance on their primary instrument. The 22 NAP subjects had an average age of 21.5±5.5 and an average of 11.0±6.5 years experience playing their primary instrument.

2. Screening for note naming ability

The following test was used to verify the claims of subjects who reported to possess AP. The method is similar to those used by Baharloo *et al.*[5] and Gregersen *et al.* (personal communication). We used a predefined criterion of 80% accuracy to qualify a subject as an AP possessor.

The test required subjects to orally name 60 musical notes. The tones were presented in six blocks of ten notes each. Between blocks, subjects were allowed to rest for as long as desired. Notes were pseudo-randomly selected with replacement from within the range of C2–C7 (65.4–2093.0 Hz) such that no consecutive notes were within nine whole steps of each other and no note values repeated within any five-note span. All stimuli had a duration of 500 ms with an interstimulus interval of 2100 ms. Subjects were asked to label orally the musical note name (without regard to octave) of each stimulus (e.g., ‘‘F’’ or ‘‘B^b’’) during the interstimulus interval. Responses were manually recorded by the experimenter and equivalent enharmonic labels were accepted as correct (e.g., ‘‘G^b’’ vs. ‘‘$F^\#$’’). The test was administered using PsyScope 1.2.1 with a script that was identical for all subjects. To minimize the success of skilled RP musicians, subjects were not given a reference tone and at no time during the experiment was any sort of feedback provided.

The first 30 stimuli consisted of sinusoidal tones. The notes were generated using the ‘‘tone generator’’ function of SoundEditII (SEII) for the Macintosh. Frequency values were based on the equal-tempered scale with $A_4 = 440$ Hz. The next 30 stimuli consisted of piano tones. The tones were generated using a Roland JV-50 synthesizer. In order to control for note duration and envelope the tones were recorded directly into SEII from a Finale ’98 file. Fundamental frequency values were again based on an equal-tempered scale with $A_4 = 440$ Hz.

Data were scored in terms of percent accuracy. Accuracy was measured for each subject as the proportion of the total stimuli that received correct responses (i.e., omitted notes were considered incorrect).

Twenty subjects qualified as AP possessors, performing with an average of 91%±7% accuracy (range: 80%–100%; chance=8%). Eighteen subjects claiming not to possess AP performed at 9%±6% (range: 2%–20%).[20]

3. Stimuli and procedure

Subjects were played a tone followed by a silent interval of varying length (either 2, 8, or 32 s). At the end of the ISI a nontonal auditory click (similar to the striking of wooden block; duration ~100 ms) was sounded, indicating that participants should reproduce the original target frequency by adjusting the knob of a digital sine-wave function generator. Subjects were explicitly instructed that they should try to match both the chroma and octave but that chroma was more important (i.e., that it was better to reproduce the chroma accurately in the wrong octave then to get the octave correct but lose the exact chroma). Before each stimulus, the function generator was reset to a frequency of 1000 Hz. Subjects indicated successful completion of the task either orally or by tapping their finger on the top of the function generator. The experimenter recorded the participants' responses manually and was not aware of the correct frequency values.

Ten target tones were played for each condition in a fixed order (2s, 8s, 32s, 2s,...). The target stimuli consisted of pure tones generated using the frequency generator function of SoundEditII (SEII) for the Macintosh. Targets were selected from a set of 120 possible tones. Sixty tones were notes from the Western, equal-tempered scale ($A_4 = 440$), ranging from C2 to B6 (65.4 to 1975.5 Hz). A second set of 60 tones was then generated by deliberately mistuning the original notes upwards by a variable amount (ranging from 20 to 80 cents). The unfamiliar tones had a frequency range from 66.4 to 2060.6 Hz. Tones were presented binaurally for a duration of 300 ms. Within each experiment, targets were pseudo-randomly selected, with replacement, so as to include an equal number of familiar and unfamiliar tones from each octave. Consecutive target tones were never within a half step (or octave ± 1 half step) of each other.

An identical computer script was used for each participant. To prevent visual monitoring of the function generator, participants were blindfolded during the performance of all tasks. Individuals were not given feedback on their performance until the completion of all tasks and at no time was a reference tone provided.

In the abbreviated version of the experiment, subjects were presented eight tones each for 2-, 8-, and 16-s ISI's and targets were drawn from between C3 and B6. All other parameters were the same.

4. Data processing

Because we were primarily interested in the encoding of chroma and sought to avoid the confounding influence of octave errors, subjects were instructed that reproducing the chroma exactly should be their priority. Accordingly, each response was corrected to the nearest octave. This correction is consistent both with the majority of AP studies[2,13,19,21–23] and with physiological evidence supporting the concept of octave equivalence.[24–27] This manipulation is unlikely to confound group differences given the substantial body of literature that fails to find differences between AP possessors and nonpossessors in the frequency of octave errors (cf. Ref. 9). After octave correction, the response distance from the target stimulus was calculated in half steps (hs) away (where a half step is defined as $\frac{1}{12}$ of the distance of an octave).[28] Half steps were chosen as a convenient and familiar unit of measure that respects the fact that our perceptual response to musical sound frequency is logarithmic. It is important to note, however, that this measure is independent of any specific musical values—it is used solely as a means of quantifying distance.

Individual performance was judged using constant error (CE) as a measure of bias and standard deviation (σ) as a measure of variability. Accurate performance would be expected to yield a normal distribution of responses that is centered at zero (low CE and low σ). In contrast, random performance (i.e., if responses bore no relationship to the original target) would be expected to produce a uniform distribution from -6 to $+6$ hs. Thus, it would have a low CE but high variability.

Given the expected distributions for accurate and inaccurate performance (and the potential for deviation from normality), the median of the positive distribution (MPD) was used to determine whether observed distributions differed from the prediction of the null hypothesis. Accurate performance should have a MPD close to 0 whereas chance performance would have a MPD near 3. Group performance was compared to the null hypothesis by calculating a simple z score from the average and standard error of MPD values (where $z = |3-\mu|/\mathrm{SE}$). Group differences for CE, σ, and MPD were calculated using standard ANOVAs.

B. Results and discussion

Histograms of combined AP and NAP performance for each time interval are shown in Fig. 1. AP subjects performed at $(\mathrm{CE} \pm \sigma) -0.14 \pm 0.47$, 0.05 ± 0.44, and -0.02 ± 0.47 hs and NAP subjects performed at -0.05 ± 2.14, -0.23 ± 2.53, and -0.13 ± 2.10 hs for time intervals of 2, 8, and 16/32 seconds.[29] ANOVA with CE as the dependent variable[30] (G-G $\varepsilon = 0.89$) showed no significant effect of group [$F(1,40) = 0.35$; $p > 0.50$] or time interval [$F(2,80) = 0.08$; $p > 0.90$]. There was no interaction between group and time interval [$F(2,80) = 2.39$; $p > 0.10$]. ANOVA with σ as the dependent variable (G-G $\varepsilon = 0.91$) showed a significant effect of group [$F(1,40) = 68.26$; $p = 0.0001$] but not of time interval [$F(2,80) = 2.41$; $p = 0.10$]. The interaction between group and time interval was not significant [$F(2,80) = 3.13$; $p = 0.05$].

The AP subjects performed at $(\mathrm{CE} \pm \sigma) -0.04 \pm 0.45$ and -0.03 ± 0.48 for in-tune and mistuned stimuli, respectively. NAP subjects performed at -0.29 ± 2.10 and 0.08 ± 2.31. None of these differences was significant.

The average MPDs of the AP subjects were (avg. ±se): 0.33 ± 0.03, 0.29 ± 0.03, and 0.33 ± 0.04 for the three time intervals, and for the NAP subjects 1.48 ± 0.25, 1.55 ± 0.23, and 1.26 ± 0.21. All of these values differ significantly from the prediction of the null hypothesis. An ANOVA with MPD as the dependent variable (G-G $\varepsilon = 1.00$) showed a significant effect of group [$F(1,40) = 27.84$; $p = 0.0001$] but not of time [$F(2,80) = 0.82$; $p > 0.40$]. The interaction between group and time was not significant [$F(2,80) = 1.19$; $p > 0.30$].

These data show that the AP group was more consistent than the NAP group in their ability to reproduce the target tones. This difference may be accounted for by the experimental setup—specifically, because the frequency generator was always turned on at 1000 Hz and the output function was continuous, there was a small amount of tonal interference intrinsic to the task. NAP subjects frequently reported this to be distracting. In both groups, it is likely that this interference led to some degree of a gap between subjects' ability to *remember* tones and their ability to *reproduce* the tones accurately using the experimental setup. Nevertheless,

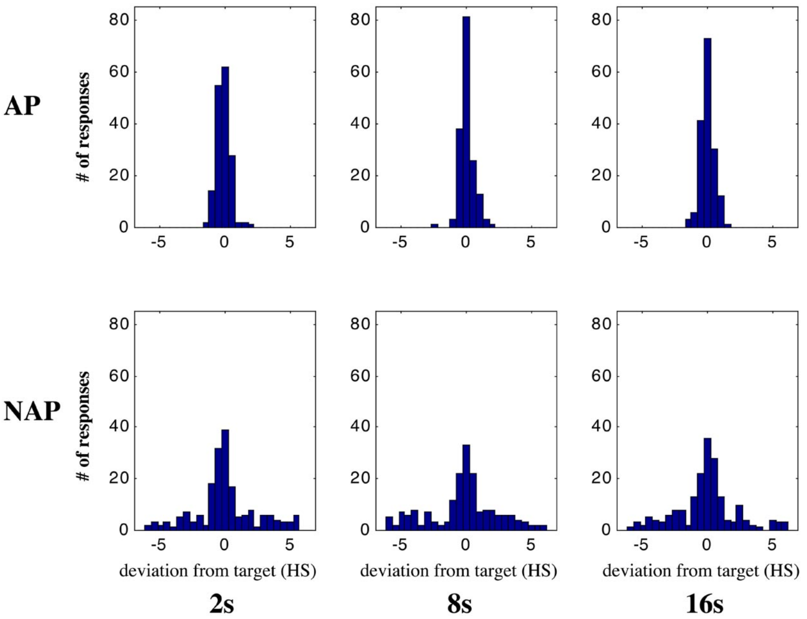

FIG. 1. Experiment 1: Histogram of responses by the AP and NAP groups for silent delays of 2, 8, and 16/32 s. Accurate performance would appear as a normal distribution that is centered at zero with little variability. Random performance would be a uniform distribution from -6 to $+6$.

both groups demonstrated that they *were* able to reproduce the target stimulus accurately with our experimental apparatus. Further, data show that neither group's performance diminished significantly *below their own baseline* with time intervals of up to 32 s. These data are consistent with previous literature in pitch memory.[17,31]

III. EXPERIMENT 2

In this experiment we tested whether subjects could reproduce a stimulus frequency accurately after passive exposure to interfering tones. Four conditions were used, each with an increasing number of distracting tones. Given that neither AP nor NAP performance was significantly affected by an increased time delay, any decrease in performance on the present task must be attributed to the effect of the distracting tones on the maintained memory trace.

A. Method

Experiment 2 differed from experiment 1 by filling the ISI with a variable number of distracting tones. Four conditions were created: a 2-s ISI with 1 distracting tone; a 4-s ISI with 11 distracting tones; an 8-s ISI with 31 distracting tones; and a 16-s ISI with 71 distracting tones.[32] The distracting tones were randomly selected from the 120 stimulus tones and presented for 200 ms each. There was a 200-ms interval between the target tone and the first distractor and a 1600-ms interval between the last distractor and the cue for subjects to reproduce the target stimulus. Again, ten target tones were played for each condition in a fixed order (2 s, 4 s, 8 s, 16 s, 2 s,...). In the abbreviated version, eight tones each were presented in 2-, 8-, and 16-s conditions. All other parameters were the same as in experiment 1.

B. Results and discussion

Histograms of AP and NAP performance for each time interval are shown in Fig. 2. AP subjects performed at -0.04 ± 0.60, -0.35 ± 0.97 (three subjects only), 0.00 ± 0.58, 0.05 ± 0.76 hs and NAP subjects performed at -0.05 ± 2.43, 0.27 ± 2.29 (six subjects only), 0.25 ± 3.19, 0.22 ± 3.18 hs for the four time intervals. ANOVA with CE as the dependent variable (G-G $\varepsilon=0.96$) showed no effect of group $[F(1{,}40)=0.88;\ p>0.30]$ or time $[F(2{,}80)=0.47;\ p>0.60]$ and there was no interaction between group and time $[F(2{,}80)=0.34;\ p>0.70]$. ANOVA with σ as the dependent variable (G-G $\varepsilon=0.89$) showed significant effects of group $[F(1{,}40)=385.66;\ p<0.0001]$ and time $[F(2{,}80)=6.16;\ p<0.01]$ as well as a significant interaction between group and time $[F(2{,}80)=4.53;\ p<0.025]$.

The AP subjects performed at $(\mathrm{CE}\pm\sigma)$ -0.03 ± 0.73 and -0.04 ± 0.68 for in-tune and mis-tuned stimuli, respectively. NAP subjects performed at -0.10 ± 2.98 and 0.34 ± 2.83. None of these differences was significant. These data illustrate that stimulus intonation did not have any consistent effect on the performance of either AP or NAP subjects.

The average MPDs of the AP subjects were 0.31 ± 0.03, 0.48 ± 0.14, 0.39 ± 0.04, and 0.44 ± 0.06 for the four time intervals; for the NAP subjects they were $1.63\pm.29$, 1.30 ± 0.17, 2.73 ± 0.17, and 2.86 ± 0.19. The AP values differed from the null hypothesis at all four time intervals. The NAP group differed from the null hypothesis for the first two time intervals but not the third $(p>0.05)$ or fourth $(p>0.20)$. An ANOVA with MPD as the dependent variable (G-G $\varepsilon=0.77$) showed significant effects of group $[F(1{,}40)=207.44;\ p=0.0001]$ and time $[F(2{,}80)=9.63;\ p<0.001]$. The interaction between group and time was also significant $[F(2{,}80)=6.54;\ p<0.005]$.

Because there was a trend towards increased musical experience in the AP group, additional analyses were conducted to evaluate the extent to which total years of musical experience and the age at which a subject first began musical training affected performance on our paradigm (see Fig. 3). Neither of these variables was well correlated with subjects' average performance for the tasks with interfering tones (for years experience, $r^2=0.16$; for age of onset, $r^2=0.36$). Similarly, there was no significant correlation of either of

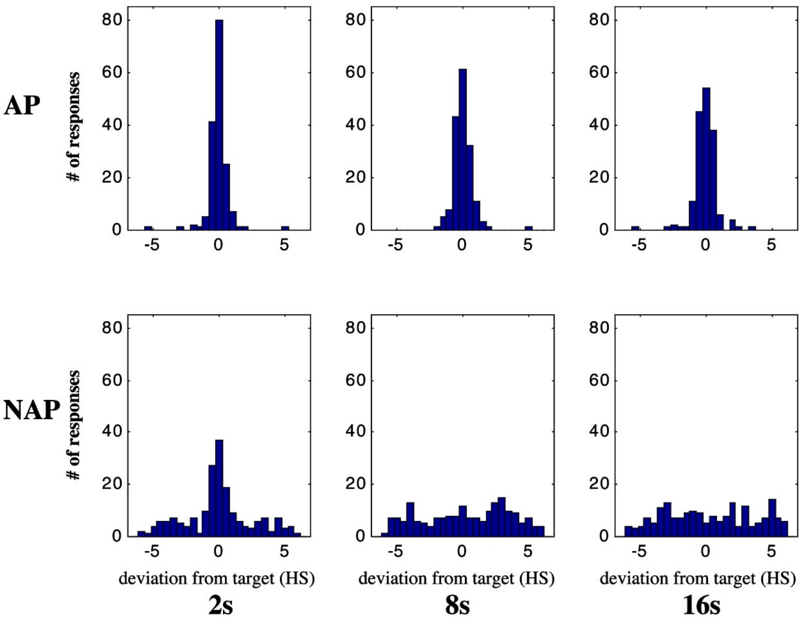

FIG. 2. Experiment 2: Histogram illustrating the distance away from target of responses by the AP and NAP groups with 1, 31, and 71 interfering tones.

these variables for within-group analyses (for AP subjects, $r^2 = 0.01$ and 0.16 for years experience and age of onset, respectively; for NAP, $r^2 = 0.02$ and 0.03). It should also be noted, in stark contrast to the idea of a ‘‘critical period’’ during which training must take place to develop AP (e.g., Refs. 11, 33, and 34), that two of our best AP possessors (both of whom scored perfect on the note-naming test and near perfect on the reproduction experiments) began training at ages 10 and 12, respectively.

While these data illustrate clear effects of group, they do not address whether this paradigm would be suitable to distinguishing between AP and NAP possessors at an individual level. To this end, data were separately analyzed for each subject as the average of the two conditions with the highest amount of interference (i.e., the 8- and 16-s intervals in experiment 2 with 31 and 71 interfering tones). The AP subjects had an average σ of 0.66 with a range of 0.27–1.43 and a median of 0.59. The NAP subjects had an average of 3.18 with a range of 2.31–3.82 and a median of 3.19. Thus, there was a gap of almost one full standard deviation between the worst performance by an AP subject and the best performance by an NAP subject; the group medians suggests an even wider gap between prototypical AP and NAP possessors.

These data confirm at the individual level the major effect of the group analysis: AP and NAP subjects were differentially affected by the presence of interfering tones. With a large number of distracting tones, NAP performance was indistinguishable from chance. Only the AP subjects were able to remember and reproduce stimuli accurately after the initial sensory trace was destroyed. These data are consistent with previous research[13–16,18] and support the notion that this

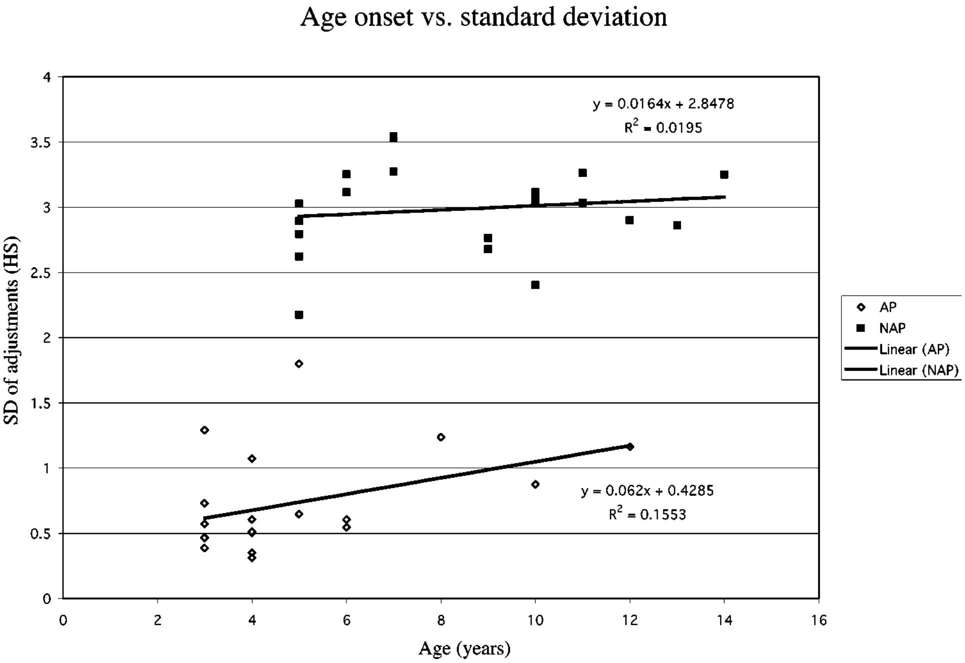

FIG. 3. Correlation between age of onset of musical training and standard deviation of performance for experiment 2. AP subjects are represented by squares and NAP subjects by triangles. Solid lines represent the linear regression indicated by the equations.

paradigm may be an effective way to identify individuals as either possessors or nonpossessors of AP.

IV. DISCUSSION

In this paper, we present a paradigm that is able to distinguish accurately between AP possessors and nonpossessors without requiring subjects to make use of any knowledge of musical nomenclature. Many previous data support the theoretical basis of this paradigm. Principally, Bachem[18,35] argued that the fundamental difference between AP possessors and nonpossessors is that NAP individuals are able to encode only the height of tonal stimuli whereas AP individuals encode representations of both height and chroma. Further, Bachem was careful to point out that this skill could not be acquired—rather, he characterized pseudo-AP (that which could be learned later in life) as the ability to become particularly adept at encoding height. However, this skill allows individuals to encode frequency at best to a precision of 5–9 semitones. Given that our paradigm corrected all responses to the proper octave, this level of precision would be ineffective. Instead, the accuracy of responses should reflect subjects' precision at encoding and then reproducing the chroma of the targets. Over the years, a significant body of data has accrued that corroborate Bachem's original assertion: AP and NAP individuals are comparable at performing tasks that involve echoic or short-term memory, but only AP possessors are able to encode and maintain an accurate long-term representation of stimulus chroma.[13–16,18,19,31]

Additional theoretical support for our paradigm comes from Takeuchi and Hulse (Ref. 33, p. 353) who discuss the many factors (e.g., timbre, chroma, and height) that may affect individuals' absolute pitch abilities, and suggest that susceptibility to these factors may be a hallmark of ''lower'' forms of AP (this is comparable to Bachem's description of ''limited universal'' absolute pitch[35]). In contrast, Takeuchi and Hulse suggest that the ability to reproduce accurately the absolute frequency of stimuli may be a hallmark of ''higher'' forms of AP. Obviously, as originally intended by the authors, this would not be a suitable means to test for AP in nonmusicians because it requires subjects to have memorized specific frequency values. However, in conjunction with the findings of Bachem and others, it is reasonable to believe that if subjects were given a target to remember, followed by an imposing interval that destroyed their short-term trace of the stimulus, this may be an excellent way of testing for AP. Reasonable options for such an interval could be either a very long delay (on the order of minutes, hours, or days), although this would be experimentally prohibitive for any large-scale study, or, alternatively, some sort of tonal interference (which is known to destroy rapidly the ability of normal individuals to maintain a tonal representation).

It should be emphasized that this skill is *not* equivalent to the ''latent AP'' described by Levitin and others.[36–38] Paradigms used by those groups test the ability to evoke the memory of a specific, spectrally complex stimulus that has accumulated across many repeated presentations. In contrast, the present paradigm explicitly isolates the ability to encode an immediate representation of stimulus fundamental frequency without the presence of any extrinsic cues. Elsewhere, we expand on the significance of this difference and present a new model of AP that identifies subpopulations within the traditional group of note namers and describes the differential effects of timbre, chroma, and intonation on subjects' ability to encode accurate representations of stimulus frequency. We believe this model may help reconcile conflicting views on the etiology of AP.[39]

There are several important applications of the new experimental paradigm presented here. Foremost, use of this paradigm may be able to provide key information in resolving the dispute on the etiology of AP. Advocates of the early-learning theory have argued that musical training is required in order to develop AP. Thus, the only way to rigorously test this theory would be to test for AP in individuals both with *and without* musical training. However, as long as the ability to name notes is considered the hallmark of AP, such a test will be impossible—only individuals with musical experience will be able to pass the test (cf. Ref. 12). Perhaps a better definition of AP—based on Bachem's original description—would be as the ability to encode (and reproduce) durable representations of the chroma of periodic stimuli. To prevent confusion with traditional definitions of AP, we might refer to this skill as the ability to perceptually encode, or APE.

Obviously, this revised definition would include all individuals capable of passing conventional AP tests. It would also include those individuals who are commonly recognized as AP possessors but who cannot name notes accurately according to the Western equal-tempered system based on $A_4 = 440$ Hz—such as musicians of non-Western training or AP possessors whose sense of pitch has shifted with age[1,40] or medication.[41,42] Elsewhere, we have presented data that demonstrate a dissociation between the ability to name notes and the ability to encode meaningful representations of stimulus frequency.[39,43] Importantly, being more inclusive, under our definition it should also be possible to test whether musical training is required to develop APE. Indeed, the paradigm presented here may be ideally suited for this purpose.

V. CONCLUSION

All previous tests of AP have required subjects to possess some degree of musical expertise—as such, it has never been possible to test the hypothesis that early musical training is required to develop AP. We present a new paradigm that does not require subjects to make use of any musical knowledge or experience. Data from over 40 classically defined AP and NAP musicians strongly support the validity of this method.

Because it does not require labeling of notes, this new paradigm may be usefully applied in several ways—in quantifying more accurately than heretofore the prevalence of AP, in genetically assessing the possible hereditary contribution to AP, and, perhaps most centrally, in determining the extent to which musical experience is, or is not, needed to develop AP. To the best of our knowledge, this is the first test explicitly designed as a possible way of detecting AP in nonmusicians. Given the performance of experienced musicians with and without AP, it would be of great interest to discover a nonmusician who is able to perform accurately on this test.

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[30] For this and all other tests (unless otherwise specified) we used a repeated-measures ANOVA, with AP/NAP status as a between-group factor and time interval as a within-group factor. To account for possible violations of sphericity, Greenhouse–Geisser (G-G) corrections were calculated and the corrected p-values are reported in the main text.

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