# Musical Activity Tunes Up Absolute Pitch Ability

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# Musical Activity Tunes Up Absolute Pitch Ability

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**Absolute pitch (AP) is the ability to identify** or produce pitches of musical tones without an external reference. Active AP (i.e., pitch production or pitch adjustment) and passive AP (i.e., pitch identification) are considered to not necessarily coincide, although no study has properly compared these abilities. Using a novel computerized pitch adjustment test, we investigated active AP ability in musicians with and without AP (ages 18-43). We found a significant correlation between active and passive AP indicating that AP possessors (APs) identify and produce pitch equally well. Furthermore, we found that APs generally undershoot when adjusting musical pitch, a tendency that decreases when musical activity increases. Finally, APs are less accurate when adjusting the pitch to black key targets than to white key targets. Hence, AP ability may be partly practice-dependent and we speculate that APs may benefit from frequent contact with fixed standard chroma to keep in tune.

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**Key words:** absolute pitch, perfect pitch, musicians, pitch production, music

Absolute pitch (AP) is commonly defined as the ability to identify the pitch of a musical tone or to produce a musical tone at a given pitch without the use of an external reference pitch (Takeuchi & Hulse, 1993). Individuals with AP presumably possess an internal pitch template (IPT) that enables them to map musical tones to linguistic labels (so-called "active AP") and to identify and label musical tones (so-called "passive AP") (Ward, 1999). For more than a century, numerous studies have investigated pitch identification ability in absolute pitch possessors (APs) in terms of accuracy (Abraham, 1901; Petran, 1932), frequency range (Rakowski & Rogowski, 2011), speed (Miyazaki, 1990), influence of timbre (Miyazaki, 1989; Vanzella & Schellenberg, 2010), difference between black and white key notes (Baird, 1917; Takeuchi & Hulse, 1991), and searched for the neural correlates (Dohn et al., 2013; Ohnishi et al., 2001; Schlaug, Jancke, Huang, & Steinmetz, 1995; Wilson, Lusher, Wan, Dudgeon, & Reutens, 2009; Zatorre, Perry, Beckett, Westbury, & Evans, 1998;) and associated personality traits of AP (Dohn, Garza-Villarreal, Heaton, & Vuust, 2012). For reviews on AP, see also, Takeuchi and Hulse (1993) and Ward (1999).

Since the earliest days of AP research, a distinction has been made between active AP and passive AP (Abraham, 1901). Active AP refers to the task of assigning an auditory pitch to a given pitch name whereas passive AP refers to the task of assigning a pitch name to a given auditory pitch (Parncutt & Levitin, 2009). Thus, the two abilities have inverted stimuli-response tasks, yet they are based on the same mechanism in linking an auditory pitch and a pitch name. Active AP can be assessed using a pitch production task (singing or playing) or by adjusting the frequency of a tone generator whereas passive AP commonly is assessed using a pitch identification test (Parncutt & Levitin, 2009; Takeuchi & Hulse, 1993). The relationship between active and passive AP, however, has not been properly investigated and relatively little is known about active AP since few studies have investigated this ability. Therefore, two fundamental questions, with strong implications for research in AP ability, remain unanswered.

First, no evidence supports the often repeated claim that active and passive AP are two separate abilities that do not necessarily coincide (Abraham, 1901; Levitin,

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1994; Parncutt & Levitin, 2009; Rakowski, 1978; Rakowski & Rogowski, 2011; Révész, 1953; Takeuchi & Hulse, 1993). In fact, no study has compared active and passive AP abilities across all 12 pitch classes and tested for a possible correlation in performance within the same sample of subjects. Thus, the first question is: does active AP ability as measured by a pitch adjustment test differ from passive AP ability as measured by a pitch identification test?

Secondly, as most musical instruments (e.g., a piano) possess a pitch template of 12 different tones (within an octave) that they can produce, it has been proposed that APs similarly possess an internal pitch template (IPT) from which they reference and retrieve musical pitch (Hsieh & Saberi, 2008; Levitin, 1994, 2004; Levitin & Rogers, 2005; Ward, 1963a, 1999). As musical instruments can be tuned to different concert pitch standards (e.g., $A_4 = 440$ Hz), the tuning of the IPT in APs (as measured by the mean deviation to the equal tempered system with the concert pitch standard defined as $A_4 = 440$ Hz) may differ between APs given that a substantial shift in pitch perception in the "sharp" direction (pitch perceived higher than it physically is) has been reported in APs above the age of 50, supposedly due to an age-related change in the basilar membrane (Athos et al., 2007; Vernon, 1977; Triepel, 1934, as cited in Ward, 1999). However, it remains unknown whether aging and other factors may affect the tuning of the IPT in APs below the age of 50. Individual factors, such as the age of onset of music training (known to correlate with AP accuracy, Miyazaki, 1988; Sergeant, 1969) or the amount of musical activity (known to enhance other musical abilities, Fujioka, Trainor, Ross, Kakigi, & Pantev, 2004; Trainor, Shahin, & Roberts, 2003), may influence the IPT tuning. Also, universal factors, such as the different occurrence of the pitch classes in Western music in general (also reported to correlate with AP accuracy, Simpson & Huron, 1994) could be involved. Hence, the second question is: which individual and universal factors influence the tuning of the IPT in APs below the age of 50?

Interestingly, the tuning of the IPT in APs has never thoroughly been investigated using a proper fine-grained pitch adjustment test (PAT) incorporating all 12 pitch classes of the chromatic scale. Furthermore, no study has investigated the pitch classes per se with regard to differences in their "pitch standard" (i.e., the "zero point" of the tones) and to differences in adjustment difficulty. Here, we introduce a novel paradigm using a PAT that adequately answers these questions.

Active AP can be approached in two ways: physiologically by singing (or humming or whistling) or technically by adjusting the frequency of a pitch generator (e.g., an oscillator) (Parncutt & Levitin, 2009; Takeuchi & Hulse, 1993). Numerous studies have used singing to measure the accuracy of AP ability (Abraham, 1901; Gough, 1922; Weinert, 1929, as cited in Petran, 1932; Wynn, 1971, 1972); however, later studies have shown that even musicians without AP (non-APs) may possess good long-term memory for pitch when measured by singing (Halpern, 1989; Levitin, 1994). This finding was strongly supported by a recent study by Hsieh and Saberi (2008), who examined pitch-production accuracy (as measured by the average deviation to target pitch) in APs and non-APs using both production mechanisms. They found that the APs clearly outperformed the non-APs in their pitch production task using adjustment of a pitch generator, whereas both groups (APs and non-APs) were highly accurate in the vocal production task. This finding suggests that singing may not be a reliable method for measuring AP accuracy. Instead, adjusting the frequency of a pitch generator is preferable when investigating active AP ability.

Most of the previous studies using a pitch generator to examine pitch production ability had limited technological resources at their disposal due to the time of their execution. Baird (1917) and Petran (1932) used an apparatus called "Tonvariator" (i.e., a preliminary pitch generator) that worked with a stream of compressed oxygen of constant pressure through a glass y-tube, providing a pitch adjustable in frequency though in only one direction at a time (Petran, 1932). Thus, the subject had to choose a direction in which the pitch should be adjusted to match the requested target note. The subject listened to the pitch glide and said "There" when it reached the target pitch and the experimenter read the level of water in the attached manometer tube and calculated the final frequency. Baird (1917) did not present results from the six participating APs in full, yet he stated that the accuracy in pitch production corresponded "fairly well" to the accuracy in pitch identification. On the other hand, Petran (1932) concluded that the results from the two tests did not correspond at all, although he only tested pitch production for the accuracy to the tone $A_4$ (concert pitch). van Krevelen (1951) used an oscillator to compare identification and production ability in APs; however, only three tones were applied as targets in both tests (G#, A, and A#). Using this paradigm, testing methods were compared and pitch production was found to have the highest accuracy, but no conclusions were made regarding the participants' performance across the two tests. Rakowski (1978) also examined pitch production with a limited number of tones, with the exception of one experiment in which the participants were asked to tune a tone generator to 12 chromatic tones of a middle octave. However, this particular experiment included only three AP subjects. Based on this study, he reported a tendency to raise the pitch of low notes and lower the pitch of high notes within one octave, a finding that has not been supported elsewhere. No direct analysis comparisons to results from the pitch identification test were made. Hsieh and Saberi (2008), the only recent study on this matter, used both singing and a pitch generator (i.e., a computer program with a GUI slider) to explore pitch production ability in five APs and five non-APs. The primary aim of this study, however, was comparing the pitch production methods and thus no direct analysis comparisons to results from the pitch identification test were reported. Hence, it remains unknown whether APs are equally capable of identifying and producing pitch, which may be due to the lack of a qualified paradigm solving this problem.

For practical reasons, a pitch identification test (PIT) has been the most common way to measure AP since it quickly and easily distinguishes APs from non-APs without use of advanced equipment. In fact, only an instrument or the play-back of a recorded sequence of tones is needed. Such a test can be completed within a few minutes and provides some information about the putative AP ability, simply derived from the error rate of the performance. Although such a simple (quite uncontrolled) test may not be the optimal way of testing for AP, it certainly remains more trustworthy than the use of self-reporting, on which some studies have relied. Additional information of the AP ability, such as response time, can be gathered accurately using a computer. This measure has been found useful in exploring the diversity of AP ability (Bermudez & Zatorre, 2009). However, when a thorough investigation of AP ability is needed with detailed information on individual performance both in terms of accuracy, consistency, and level of IPT, then a PAT becomes advantageous. An important limitation of a PIT is the substantial difficulty in dealing adequately with differences in IPTs in APs (Takeuchi & Hulse, 1993; Ward, 1999) as well as with the fact that some APs have encountered a severe shift in their pitch perception due to age. For example, Triepel (1934, as cited in Ward, 1999) and Vernon (1977) reported that from about age 50 they began to perceive music one or two semitones too sharp. These findings were recently corroborated by Athos et al. (2007) who, in a sample of 981 AP subjects, found a gradual decline in pitch naming accuracy with age in the "sharp" direction putatively due to an increase in the elasticity of the basilar membrane. Several models have attempted to circumvent this issue by accepting semitone errors (optionally limited to only half or ¾ point), although this does not segregate APs that consistently identify pitches a semitone too high or a semitone too low from those who, less consistently, vary in accuracy by a semitone (in both directions) (Takeuchi & Hulse, 1993; Ward, 1963a). Another model is to calculate the average error in semitones, yet this does not necessarily take into account the consistency of the direction of error (Carpenter, 1951; Ward, 1963a).

In contrast, a PAT allows for testing these additional dimensions of AP ability, thus providing valuable insight into the tuning of the IPT in the AP possessor. For example, a PAT easily detects if an AP possessor consistently aims 25 cents too low on all 12 pitch classes (compared to an equal-tempered tuning system with an $A_4$ of 440 Hz). Only Weinert (1929, as cited in Ward, 1963a) has dealt with this in a PIT by calibrating the test stimulus to the individual "zero point" of each subject (i.e., the tuning of the IPT). However, this is a tedious process that includes running the whole experiment twice. A PAT is not necessarily much more time consuming than a PIT, yet it provides a more accurate description of the AP ability in three different measures of the ability simultaneously: 1) the tuning of the IPT as indicated by the mean deviation (not disregarding sign) from target pitch, 2) the accuracy to target pitch, as indicated by the mean absolute deviation from the fixed standard frequency, and 3) the consistency, as indicated by the standard deviation from the individual's own IPT. Moreover, a fine-grained PAT does not struggle with the ceiling effect that a standard PIT does when testing highly skilled AP possessors (who may easily obtain 100% correct as in, e.g., Athos et al., 2007). One could argue, of course, that using response time in a PIT also eliminates the potential ceiling effect (as in, e.g., Bermudez & Zatorre, 2009); however, this measure could be affected by motor bias in the response procedure in the tested population, and besides, response time is not a measure of accuracy in the literal meaning of the word.

The primary aims and hypotheses of the present study were:

1. Comparing passive AP as measured by a standardized PIT with active AP as measured by a PAT in matched groups of APs and non-APs (and within APs only), hypothesizing that the two abilities coincide.
2. Investigating potential factors affecting the IPT tuning in APs using a novel paradigm with a computerized pitch generator across all 12 pitch classes,

hypothesizing that some factors (particularly onset of music training and musical activity) play a role.

We used a standardized and well-documented PIT, developed by Baharloo, Johnston, Service, Gitschier, and Freimer (1998), with sine wave tones and piano tones. Studies using a PIT have described a gradual shift in the IPT tuning due to aging, with a typical onset in the fifth decade of life (Athos et al., 2007; Triepel, 1934, as cited in Ward, 1999; Vernon, 1977). Accordingly, we investigated the IPT tuning of APs under the age of 50 years. Moreover, it has been suggested that AP accuracy depends on the age of onset of music training (Levitin & Zatorre, 2003; Miyazaki, 1988; Takeuchi & Hulse, 1993), and that musical activity enhances some musical abilities (Fujioka et al., 2004; Trainor et al., 2003). Therefore, we wanted to investigate whether individual factors such as onset of music training, musical activity, and musical listening influence the tuning of the IPT. Finally, reports have indicated a universal tendency towards higher AP accuracy for some notes rather than others given that the pitch classes have been found to differ in terms of ease of recognition. The black key notes are characterized by less accuracy and longer response time compared to white key notes in numerous PIT studies (Baird, 1917; Bermudez & Zatorre, 2009; Boggs, 1907; Gough, 1922; Miyazaki, 1988, 1989, 1990; Petran, 1932; Takeuchi & Hulse, 1991), which may be due to the less frequent occurrence of the black key notes in music (Simpson & Huron, 1994). Indeed, Hsieh and Saberi (2008) did find a somewhat similar result with less accuracy (greater average error) for black key notes than white key notes using a PAT; however, this result did not reach statistical significance due to the limited sample size of only five AP subjects. Therefore, we compared the black key notes with the white key notes in terms of accuracy, consistency, and tuning of the IPT as measured by the novel PAT.

## Method

### PARTICIPANTS

Thirty-nine musicians with a mean age of 29.4 ($SD = 7.0$, range = 18-43) participated in the study. They consisted of two groups: 17 musicians (3 female) with absolute pitch (APs) and 22 musicians (6 female) without absolute pitch (non-APs). The two groups were matched with regard to gender ($\chi^2 = 0.50$, $p > .20$), age ($U = 154.5$, $p > .20$), and age of onset of music training ($U = 140.0$, $p = .19$). Although the participants played different instruments as their primary instrument, all participants reported familiarity with the piano.

All participants were of Caucasian ethnicity and were native Danes. The participants all reported to be musicians and were primarily recruited through the Royal Academy of Music, Aarhus and the Music Department at Aarhus University. The study was approved by the local ethics committee (The Central Denmark Region Committees on Biomedical Research Ethics), and written informed consent was obtained from each participant after detailed explanation of the experimental procedure. All participants received compensation for being in the study.

### PITCH IDENTIFICATION TEST

To confirm self-reported AP and to distinguish APs from non-APs, all participants completed an online pitch identification test (PIT) available from Athos et al. (2007) and developed by Baharloo et al. (1998). The PIT was performed in the laboratory as part of the experiment and consisted of 80 trials: 40 randomly selected pure tones (i.e., computer-generated sine waves without overtones) and 40 randomly selected digitized piano tones. The participants were asked to listen to the presented tones through stereo headphones (Denon model AH-D750) and to identify them by responding via an onscreen piano keyboard on a Lenovo T500 laptop using an optical mouse. The participants were not allowed to sing, whistle, or hum during the test and no feed-back was given during the test.

The tones had duration of 1 s with a 2 s interlude between tone onsets. They were delivered in series of 10 tones, giving the participant an opportunity to pause between sets. Four pure tones and four piano tones were excluded from the scoring due to their position at the outermost range of the keyboard, resulting in 72 counting trials. Participants were given one point for each correct answer (maximum score for the pure tone test and the piano tone test together was 72) and ¾ point for each error of a semitone. We averaged the participants' scores in mean pure tones and mean piano tones, and those scoring above a threshold of 36 were designated APs, whereas the rest of the participants were designated non-APs. The probability of achieving a test score above this threshold of 36 in total (pure tones + piano tones) by chance alone is $1.21 \times 10^{-10}$ (see Athos et al., 2007, for calculation). Note that the mean expected score by chance is 14.25 with 95% of expected values lying between scores of 8.5 and 20.75.

### PITCH ADJUSTMENT TEST

All participants completed the pitch adjustment test (PAT). We developed a script in MathWorks MATLAB (version 7.9.0.529) that generated a continuous sine wave tone, adjustable in frequency, and controlled by a programmable, stepless USB scroll wheel (Griffin Powermate). The adjustment resolution was 1/768 per octave (0.0156 semitone resolution), and the onset frequency of the sine wave tone was randomized in each trial in the same resolution between 220 Hz and 880 Hz. Auditory stimuli were presented through the stereo headphones as used in the PIT. To ensure that the actual output frequency was identical to the displayed frequency, we tested the output sine wave tone by measuring it directly from the very same headphones with two different digital tuners (typically used for tuning an instrument, e.g., a guitar) at several frequencies. The tuners confirmed the displayed frequency of the sine wave tone (generated in MATLAB) with an uncertainty of less than 1 cent in all tests.

The PAT consisted of 36 trials in three blocks. Each block contained 12 trials with each of the 12 tones of the octave presented in random order. Before the test, a short practice test was given to acquaint participants with the speed of the scroll wheel and to adjust the volume of the computer. The participants were visually presented to the musical name of a target tone displayed by a letter (e.g., F or A) together with a corresponding, marked key on sketched keyboard excerpt. Accidentals (black-key-names) were presented with both enharmonic equivalents (e.g., G# / Ab). To prevent influence on the choice of octave, the visual stimuli did not contain any notes. One second after presentation of the name of the target tone, the sine wave tone was started (with a random frequency onset) and participants were asked to adjust the sine wave tone to match the requested target tone as accurately as possible in an octave of their own choice and to respond by pushing the pushbutton of the scroll wheel within 15 s. The sine wave tone did not stop until a response was made. If a participant did not respond within the 15 s, the sine wave tone was stopped and the final frequency was registered as a response. Both APs and non-APs typically responded after only 5-6 s and the 15-s limit was only reached in less than 2% of all trials.

The participants were told that target tones were based on an equal-tempered tuning system with an $A_4$ of 440 Hz, and they were asked to think of each tone individually and to attempt to avoid employing relative pitch from trial to trial. Also, they were not allowed to whistle, sing, or hum during the test. No feedback was given at any time during the test. APs reported that this was a somewhat easy test, though not as easy as a standard PIT, where the resolution is limited to the 12 tones of the octave. Non-APs reported that the test was very challenging, and that even if they tried to use a relative pitch cue strategy, this was extremely difficult due to the continuous sine wave tone with random frequency onset that thus served as masking in the test.

The pitch-adjustment frequencies of the participants were compared to the nearest target pitch (distance less than six semitones) since octave errors were beyond the scope of this study. The scoring procedure of the PAT provided three measures for each participant's performance, all measured in cents (i.e., hundredths of a semitone):

1. *Mean deviation* (MD) was calculated by averaging all positive (if above target pitch) and negative (if below target pitch) distances to target pitch. Thus, it reveals a measure of the **tuning of the internal pitch template**. A negative MD indicates that the participant has adjusted the pitch lower than target pitch on average, suggesting an IPT tuning below the equal-tempered tuning system with an $A_4 = 440$ Hz. Chance performance in this measure, calculated from a 1,000,000 trial Monte Carlo simulation, is 0.0 cents which corresponds to the mean of a uniform distribution, given by:

$$\frac{600 \text{ cents} - 600 \text{ cents}}{2} = 0.0 \; cents \tag{1}$$

2. *Mean absolute deviation* (MAD) was calculated by averaging all absolute distances to target pitch (i.e., contrary to MD, the positive and negative values do not neutralize each other here). This is used to measure the AP adjustment **accuracy** in relation to the target pitch, defined by $A_4 = 440$ Hz. Chance performance in this measure, calculated from a 1,000,000 trial Monte Carlo simulation, is 300.0 cents, which corresponds to the mean of this uniform distribution, given by:

$$\frac{600 \text{ cents} + 0 \text{ cents}}{2} = 300.0 \; cents \tag{2}$$

3. *Standard deviation from own mean* (SDfoM) was calculated by the standard deviation of all distances to MD. This is used to measure the AP adjustment precision in relation to the *mean deviation* of each participant. Thus, it provides a measure of the **consistency** of the estimates of participants (or "precision" cf. Bella, Berkowska, & Sowinski, 2011). This is often regarded to be the best measure of AP production ability (Levitin & Rogers, 2005; Takeuchi & Hulse, 1993; Ward, 1999). Chance performance in this measure, calculated from a 1,000,000 trial Monte Carlo simulation, is 346.4, which corresponds to the

standard deviation of this uniform distribution, given by:

$$\frac{600\text{ cents} - (-600)\text{ cents}}{\sqrt{12}} = 346.4\ cents \tag{3}$$

All three measures were calculated for each participant across all 12 pitch classes. We also calculated the same three measures for each of the 12 pitch classes across the 17 APs. The MD and the MAD were calculated similarly; however, the SDfoM was calculated using the overall MD from all 12 pitch classes of the participant as the mean.

#### PROCEDURE

The APs were primarily identified through word of mouth and through advertisements at the Danish Royal Academy of Music and the Music Department at the local university. The non-APs were found subsequently through advertisements and were selected randomly using matching criteria.

The participants were tested individually. First, they answered a questionnaire regarding age, gender, musical background (instrument, age of onset of music training, etc.), current level (amount) of music playing (practice and performance), current level (amount) of music listening, and experience with AP. The non-APs were told that they did not have to answer the questions regarding AP experience. Then, all participants completed the PAT and subsequently they completed the PIT. This order of tests ensured that participants were not given any auditory cues from the PIT that could be used as reference in the PAT since APs can sustain a pitch accurately for a long time (Bachem, 1940; Rakowski & Morawska-Bungeler, 1987) and even display a perceptual shift in their IPT after exposure to detuned music (Hedger, Heald, & Nusbaum, 2013). The APs were tested for 90 minutes as part of other ongoing experiments before the behavioral tests. No participants reported problems with either the auditory stimuli or the answering procedure in the PAT and the PIT.

#### POST HOC EXPERIMENT

We conducted a post hoc experiment with two of the participating APs to test the variability of the IPT tuning. This experiment consisted of two sessions that took place on two different days after the original experiment. At each session the participants completed the PAT with the same procedure as in the original experiment. We chose to test the APs with the outermost IPT tunings, i.e., the ones with the highest (AP1) and lowest IPT tunings (AP2).

#### STATISTICAL ANALYSIS

The three PAT measures were all computed from the value *c* (i.e., the response-deviation) that for each trial describes the distance (and direction) to the nearest target pitch in cents:

$$c = \left(\left\{\left[log_2\left(\frac{f_{selected}}{f_{target}}\right) \times N_{steps} + \frac{N_{steps}}{2}\right] mod\ N_{steps}\right\} - \frac{N_{steps}}{2}\right) \times \frac{1200}{N_{steps}} \tag{4}$$

$N_{steps}$ is the resolution of the octave (in this case 768) and *mod* refers to the modulo operation. Consequently, *c* ranges from -600 to 600. A positive value indicates that the frequency adjustment ($f_{selected}$) was above target pitch whereas a negative value indicates that the frequency adjustment ($f_{selected}$) was below target pitch. From this the three PAT measures were calculated:

##### MEAN DEVIATION (MD), A MEASURE OF THE IPT TUNING

$$MD = \frac{\sum_{i=1}^{N_{adjustments}} c_i}{N_{adjustments}} \tag{5}$$

##### MEAN ABSOLUTE DEVIATION (MAD), A MEASURE OF ACCURACY

$$MAD = \frac{\sum_{i=1}^{N_{adjustments}} |c_i|}{N_{adjustments}} \tag{6}$$

##### STANDARD DEVIATION FROM OWN MEAN (SDFOM), A MEASURE OF CONSISTENCY

$$SDfoM = \sqrt{\frac{\sum_{i=1}^{N_{adjustments}} (c_i - MD)^2}{N_{adjustments} - 1}} \tag{7}$$

Data from each group were assessed for normality with the Kolmogorov-Smirnov test and the Shapiro-Wilk test, which revealed violations of normality assumptions. Moreover, we could not assume equal variances in the PAT data given that the standard deviation per se was a measure of AP ability in pitch production. Accordingly, we used nonparametric tests for subsequent statistical analyses.

For hypothesis 1, we used Spearman correlation analysis to investigate the relation between the PIT and the PAT measures and we calculated *Z*-scores for each of the APs' PAT measures (MAD and SDfoM) assuming that the non-AP sample would give a representative measure of the distribution of the PAT scores in non-AP musicians:

$$Z_{MAD} = \frac{MAD_{AP} - \mu(MAD)_{Non-APs}}{\sigma(MAD)_{Non-APs}} \tag{8}$$

**TABLE 1.** *Performance in PIT and PAT.*

| Group | APs | Non-APs |
|---|---|---|
| | Mean (*SD*) | Mean (*SD*) |
| PIT score | 60.3 (10.7) | 15.7 (4.9) |
| PAT mean deviation | -19.5 (78.8) | -6.6 (326.0) |
| PAT averaged standard deviation from own mean | 62.6 | 319.7 |
| PAT absolute deviation from target pitch | 50.7 | 272.6 |

*Note*. Performance in the pitch identification test (PIT) and pitch adjustment test (PAT) of the groups of participants. APs = musicians with absolute pitch, Non-APs = musicians without absolute pitch. PIT score = pitch identification test score in points where maximum score is 72. The PAT is measured in cents of a semitone. The PAT mean deviation indicates the mean deviation of all estimates (i.e., the tuning of the internal pitch template). Thus, a negative mean deviation indicates that estimates on average were below target pitch. Target pitch refers to the equal-tempered tuning system with an $A_4$ of 440 Hz.

$$Z_{SDfoM} = \frac{SDofM_{AP} - \mu(SDfoM)_{Non-APs}}{\sigma(SDfoM)_{Non-APs}} \quad (9)$$

We examined the difference in response-deviations to target pitch across the 17 APs using the Kruskal-Wallis test. To investigate whether the adjustments of all APs were distributed equally around the target pitch (where MD = 0), we tested the APs' total response-deviations to the target pitch against zero using the one-sample Kolmogorov-Smirnov test.

For hypothesis 2, we used Spearman's correlation to examine the relation between the PAT MD and age, onset of music training, weekly hours of music playing, and weekly hours of music listening. We used Wilcoxon signed-rank test to investigate the difference between response-deviations to white key targets and black key targets. Effect sizes were calculated as:

$$r = \frac{Z}{\sqrt{N}}. \quad (10)$$

We used Friedman's ANOVA to test for differences within the response-deviations of each participant in the post hoc experiment.

All analyses were corrected for multiple comparisons using the Bonferroni correction for $p < .05$.

## Results

### PITCH IDENTIFICATION AND PITCH ADJUSTMENT

The descriptive statistics from the PIT and PAT measures are shown in Table 1. We found a statistically significant correlation between the PIT score and the PAT SDfoM, $r(37) = -.79$, $p < .01$ (Figure 1a), as well as between the PIT score and the PAT MAD, $r(37) = -.83$, $p < .01$ (Figure 1b). Whilst the non-APs contributed markedly to this correlation due to their poor (near-to-chance-) performance in both PIT and PAT, these correlations were nonetheless found to be statistically significant for the APs only; PAT SDfoM: $r(15) = -.58$, $p = .04$, PAT MAD: $r(15) = -.63$, $p = .02$. Thus, these findings indicate that pitch identification ability and pitch adjustment ability for AP possessors are associated with each other (hypothesis 1). It should also be

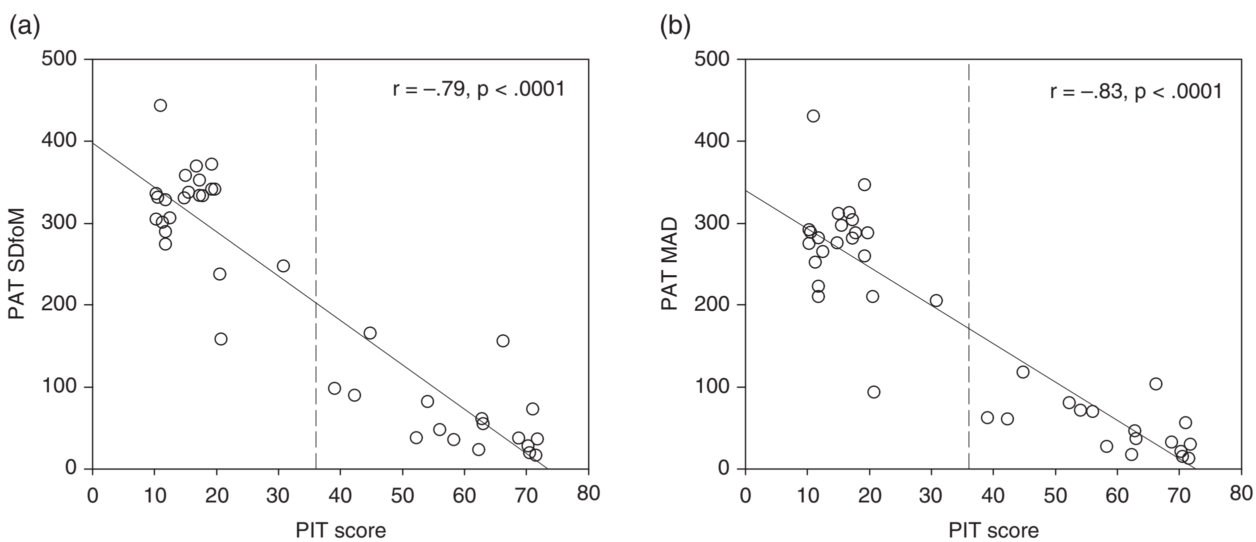


**FIGURE 1:.** Scatterplot of the pitch adjustment test (PAT) score as a function of the pitch identification test (PIT) score. A) The PAT standard deviation from own mean (SDfoM); B) The PAT mean absolute deviation (MAD).

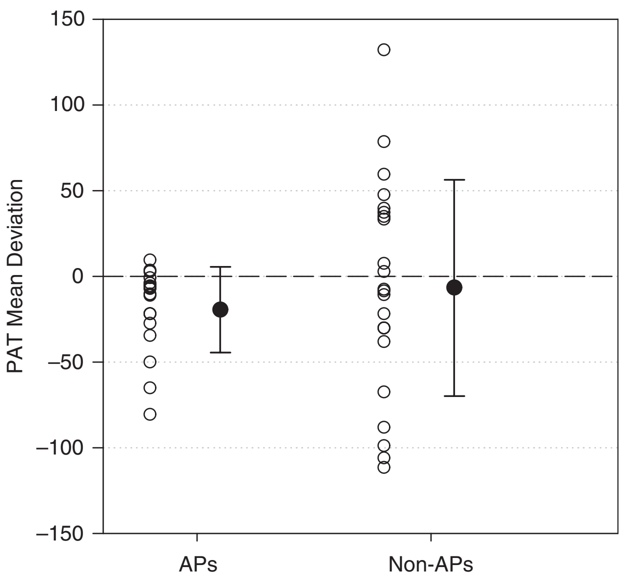


**FIGURE 2:.** Dotplot of the pitch adjustment test (PAT) mean deviation in musicians with absolute pitch (APs) and musicians without absolute pitch (non-APs). The mean deviation is also a measure of the tuning of the internal pitch template. The error bars indicate the standard deviation (of the MD across participants) and the dashed line indicates the zero point where $A_4 = 440$ Hz.

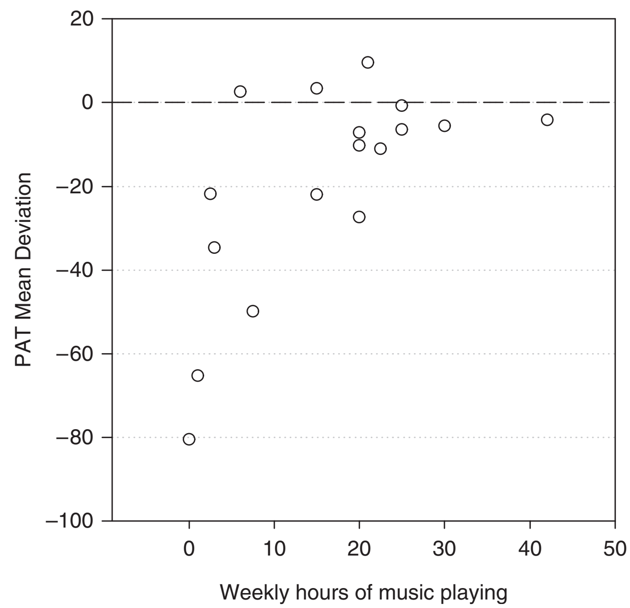


**FIGURE 3:.** Scatterplot of the mean deviation (MD) from the pitch adjustment test (PAT) as a function of the number of hours per week that the absolute pitch possessors actively played music. The dashed line indicates the zero point where $A_4 = 440$ Hz.

noted that since a high PIT score indicates strong pitch identification ability and a low PAT score (MAD and SDfoM) indicates strong pitch adjustment ability, the two abilities are actually positively correlated in reality.

We also found that all PAT *Z*-scores in APs were below -2.7 (in both MAD and SDfoM); thus, all PAT scores of the APs were more than two standard deviations away from the mean score as defined by the non-AP sample. This means that APs, defined by their extreme scores on the PIT, all exhibit outlier performance on the PAT as well.

### TUNING OF INTERNAL PITCH TEMPLATE

We found a statistically significant difference in the level of the pitch adjustments of the APs, $H(16) = 115.0$, $p <$ .01, indicating a heterogeneity in the IPT tuning of APs. We also found that the total pitch-estimates of the APs were significantly different from target pitch ($N = 612$, $Z = 2.92$, $p < .01$) (Figure 2). Additionally, it should be noted that the PAT MD of the APs ranged from -80.4 to 9.6 (median = -10.2) and that 14 out of 17 APs had a negative PAT MD. These findings show that the APs adjusted the pitch lower than target pitch on average, suggesting an overall IPT tuned lower than $A_4 = 440$ Hz.

Due to inversion of stimuli and response tasks in active and passive AP, adjusting the pitch lower (i.e., errors in the "flat" direction) in pitch adjustment tests corresponds to identifying higher (i.e., errors in the "sharp" direction) in pitch identification tests (as the verbal name of the pitch is higher than the sounding pitch regardless of the task). Hence, our data could be linked to previous findings in pitch identification studies (Athos et al., 2007; Vernon, 1977; Triepel, 1934, as cited in Ward, 1999) suggesting an age-related shift in pitch perception as revealed by this systematic error direction. Accordingly, we investigated whether this phenomenon also applied to younger individuals with AP (aged 18-43 years) using a PAT.

We found no correlation between age and PAT MD within the APs, $r(15) = .12$, $p > .20$ (Bonferroni corrected). Consequently, we investigated the effect from other factors, such as the age of onset of music training, the amount of musical activity, and amount of music listened to. We found a statistically significant positive correlation among the APs between PAT MD and the number of weekly hours of music played, $r(15) = .61$, $p = .04$ (Bonferroni corrected) (Figure 3), whereas no correlation was found between PAT MD and onset of music training, $r(15) = -.28$, $p > .20$ (Bonferroni corrected), nor between PAT MD and the number of weekly hours of music listened to, $r(15) = .16$, $p > .20$ (Bonferroni corrected). These findings suggest that the

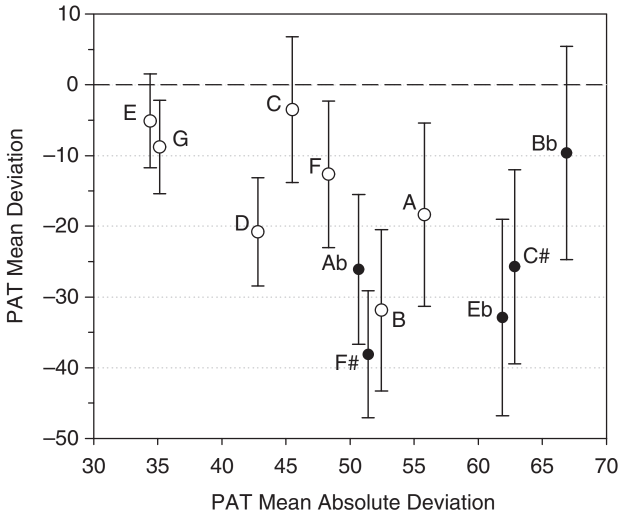


**FIGURE 4:.** Scatterplot of the mean deviation (MD) from the pitch adjustment test (PAT) of the 12 pitch classes as a function of the mean absolute deviation (MAD) from the PAT. The graph is based on the estimates of the absolute pitch possessors only. The error bars indicate the standard error of the mean and the dashed line indicates the zero point where $A_4 = 440$ Hz.

accuracy of the internal pitch template of an AP musician below the age of 45 may depend on the amount that the individual actively plays music (practice and performance) per week, rather than on age (hypothesis 2).

### PITCH CLASS IN PITCH PRODUCTION

The descriptive data across the 12 pitch classes are shown in Figure 4. We found a statistically significant difference between response-deviations to white key targets and black key targets ($Z = -3.0$, $p = .01$, $r = -.19$). This result shows that the APs adjusted the pitch lower in response to the black key names than to the white key names.

Although we did not find a statistically significant difference between adjustments to white key targets and black key targets in averaged SDfoM ($Z = -2.2$, $p = .09$, $r = -.24$), we did find a significant difference in MAD ($Z = -3.1$, $p < .01$, $r = -.19$) (Fig. 5.). These findings indicate that the pitch-adjustments of the participants were less accurate in response to black key names than to white key names in terms of the absolute deviation to target pitch; however, they were not less consistent in terms of the deviation to the overall mean of the participant.

In the post hoc experiment, we found that the IPT tuning for each AP possessor (AP1 and AP2) did not differ significantly across the experiment sessions; AP1: $\chi^2(2) = 3.1$, $p > .20$, AP2: $\chi^2(2) = 2.7$, $p > .20$, respectively (Table 2). This finding supports the legitimacy and reliability of the IPT tuning of an AP possessor, as measured by our PAT.

## Discussion

In this study, we have shown that active and passive AP abilities are correlated. Moreover, the results indicate that the tuning of the internal pitch template (IPT) in absolute pitch possessors (APs) below the age of 50 is lower than the concert pitch standard of $A_4 = 440$ Hz on average. Age did not account for this lower IPT tuning, whereas the amount of musical activity correlated significantly with the IPT. The APs adjusted the pitch lower and less accurately in response to black key targets than to white key targets in a pitch adjustment test (PAT). This indicates that the tuning of IPT in APs depends on the individual musical activity as well as on universal factors such as pitch class.

The observed correlation between pitch identification and pitch adjustment abilities is at odds with the general belief that active and passive AP are two separate abilities that do not necessarily coincide (Abraham, 1901; Butler, 1982; Levitin, 1994; Petran, 1932; Révész, 1953; Takeuchi & Hulse, 1993). This result could be related to the different pitch production methods in the studies since most previous studies relied on singing as pitch production method. In an early study, Weinert (1929, as cited in Petran, 1932) found APs able to identify pitch but not able to produce pitch using singing as the production method. However, singing may not be a reliable method to assess active AP due to motor-bias and different individual singing skills. A similar reasoning applies to amusia, where poor singing capability is not tantamount to "tone-deafness" (Pfordresher & Brown, 2007; Stewart, 2008). In fact, a person may very well be able to reproduce a song on the piano but not carry a tune. On the other hand, it may be argued that our PAT is not an example of a true pitch production test (since the participants are not directly producing the pitch themselves), yet the PAT is certainly an example of measuring active AP since the participants assign an auditory pitch to a pitch name, contrary to passive AP where the participants assign a pitch name to an auditory pitch. Although music perception and production abilities may not always coincide, it is likely that in the case of AP musicians, active and passive AP abilities do coincide. Our results show that the APs tend to undershoot in the PAT compared to the concert pitch standard of $A_4 = 440$ Hz, a finding that has only been mentioned implicitly in the AP literature. Our findings are consistent with Weinert (1929, as cited in Ward, 1963a) who mentioned that 75% of all 1785 semitone

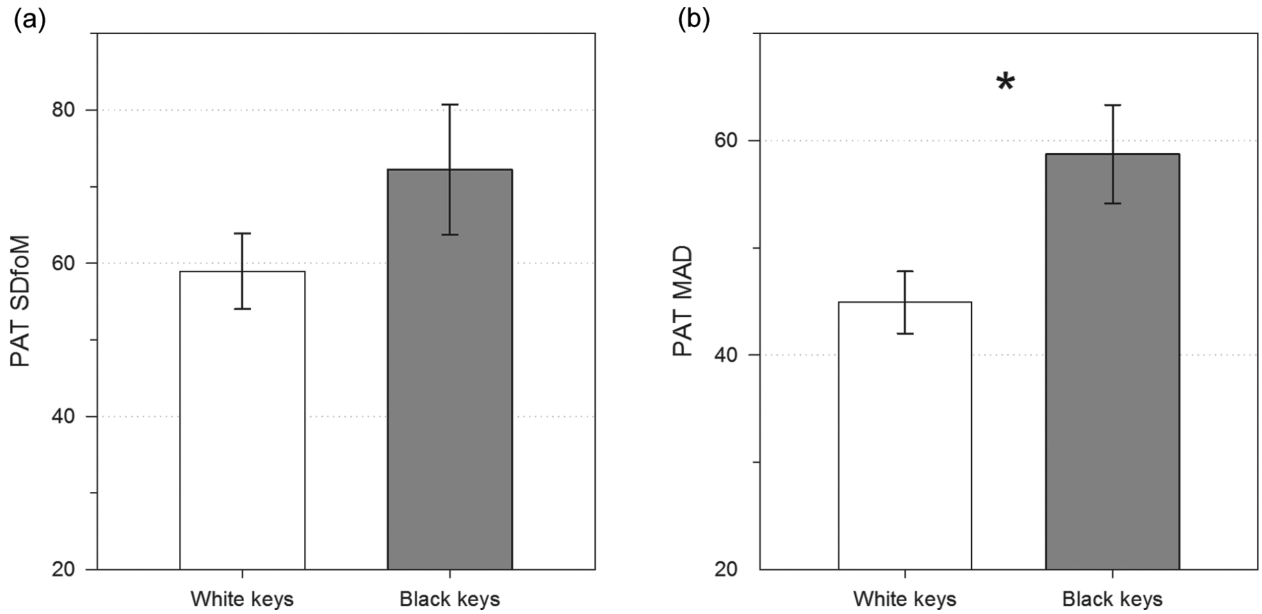


**FIGURE 5:.** Bar plots of the absolute pitch possessors' estimates in the pitch adjustment test (PAT) in response to white and black key names. a) shows the PAT standard deviation from own mean (SDfoM), and b) shows the PAT mean absolute deviation (MAD). The error bars indicate the standard error of the mean.

errors in his PIT study were "plus" errors (i.e., they mostly judged notes as being higher than the actual auditory stimulus). Consequently Ward (1963a) concluded that, on average, these 22 AP subjects were tuned lower than $A_4 = 435$ Hz. Similarly, Athos et al. (2007) showed a tendency to name the pitch too high rather than too low, and this tendency gradually increased with age. In addition, some case studies have reported a dramatic perceptual shift of the IPT tuning in the lower direction, supposedly due to aging in individuals above the age of 50 years (Vernon, 1977; Triepel, 1934, as cited in Ward, 1999). We did not find a correlation with age for our participants who were all below 43 years of age. Hence, we speculate that any gradual shift in the IPT tuning in healthy APs is not likely to occur before this age.

Some studies have further speculated that musicians, playing Baroque music with $A_4 \approx 415$ Hz or growing up with a piano tuned a semitone too low, may become accustomed to a lower tuning standard (Takeuchi & Hulse, 1993; Ward, 1999). In the present study, however, all participants reported not playing pitch-shifted music (e.g., Baroque music), nor growing up with a piano tuned differently from $A_4 = 440$ Hz.

Interestingly, we found that the general tendency in APs towards undershooting correlated with how much the APs reported to play music actively per week. While onset of music training has been found to have great impact on the development of AP as well as on AP accuracy (Levitin & Zatorre, 2003; Miyazaki, 1988; Sergeant, 1969; Wilson, Lusher, Martin, Rayner,

**TABLE 2.** *Descriptive Statistics of the* Post hoc *Tests of Two Absolute Pitch Possessors.*

| | Test | Mean deviation | *SD* | *SEM* |
|---|---|---|---|---|
| | Original | 3.4 | 27.9 | 4.7 |
| **AP1** | Post hoc 1 | 0.1 | 37.8 | 6.3 |
| | Post hoc 2 | -12.9 | 41.6 | 6.9 |
| | Original | -80.4 | 38.2 | 6.4 |
| **AP2** | Post hoc 1 | -92.7 | 28.4 | 4.7 |
| | Post hoc 2 | -88.8 | 29.8 | 5.0 |

*Note*. Descriptive statistics of the post hoc tests of two selected absolute pitch possessors, the one with the highest mean deviation (AP1) and the one with the lowest mean deviation (AP2), as measured in the original pitch adjustment test. Mean deviation also refers to the tuning of the internal pitch template measured in cents. *SD* = standard deviation, *SEM* = standard error of the mean.

& McLachlan, 2012), we found no correlation between onset of music training and IPT tuning. This indicates that early musical exposure does not determine how close an AP possessor's IPT is to concert pitch standard. Nor did we find a correlation with the number of hours of weekly music listening (e.g., from an MP3 player through headphones), which indicates that passive listening to music without contact to the reference point of an instrument does not suffice in maintaining the IPT tuning. Therefore, being regularly in touch with an instrument, and playing music actively, may be necessary to update and keep the IPT "in tune." This finding situates AP ability within the broader domain of practice-dependent expertise and is as such consistent with tests, indicating that auditory working memory in the general population is enhanced as a function of music training (Hansen, Wallentin, & Vuust, 2013; Vuust, Brattico, Seppanen, Naatanen, & Tervaniemi, 2012a; Vuust, Brattico, Seppanen, Naatanen, & Tervaniemi, 2012b;; Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010), yet working memory for musical tones is not necessarily enhanced in APs (Schulze, Mueller, & Koelsch, 2012).

Previous reports of varying frequency-estimates from day to day (Abraham, 1901; Ward, 1963b; Wynn, 1972) may challenge the idea of designating a fixed IPT tuning to a certain AP possessor. However, our post hoc experiment shows that for the APs with the highest and lowest IPT tuning in our AP group, there was no difference between the original session and the post hoc sessions in terms of IPT tuning. In fact, the participant that had the IPT tuning that differed mostly from the concert pitch standard showed a remarkable consistency in terms of low standard deviation in all sessions. In addition, this post hoc experiment acts as a litmus test of whether any of those two APs relied on relative pitch in the PAT (which would have been reflected by a low SDfoM, a high MAD, and a not-replicable IPT). This seems not to be the case here. None of the participants reported any change in their amount of musical activity at the time of the post hoc sessions compared to the time of the first session. This finding supports the reliability of the existence of an IPT tuning and substantiates the legitimacy of designating one for an AP possessor. It should be noted that the studies above reporting day-to-day variance only displayed the accuracy of $A_4$ frequency. Thus, they did not test all 12 pitch classes of the octave as we did here.

These individual differences between participants across all pitch classes in undershooting were accompanied by universal differences between pitch classes across all participants. So, although the pitch classes are equal in distance to each other (logarithmically), they are unequally difficult to identify for an AP possessor. This extends the numerous studies that have shown that black key pitches are identified more slowly and with less accuracy than white key pitches for APs (Baird, 1917; Miyazaki, 1988, 1989, 1990; Petran, 1932; Takeuchi & Hulse, 1991). In this paper we document this using pitch adjustment. The challenge of a PAT, where the auditory stimulus in the shape of a continuous sine wave tone interlinks the pitches, and thereby may blur the 12-tone template equating black and white key pitches, is of a somewhat different nature than a PIT. A PAT is completely free of any motor response bias favoring some keys over others, whereas a motor response bias favoring white key pitches over black key pitches may have affected results from previous PIT studies (according to Carroll, 1975; and Takeuchi & Hulse, 1991). Also, since we did not ask our subjects to respond as rapidly as possible, we believe to have given the subjects sufficient time to fully comprehend the key names, which may have minimized the label bias of black key names consisting of two symbols, whereas white key names only consist of one symbol.

We show here that not only are black key pitches adjusted with significantly less accuracy than white key pitches in active AP ability, black key pitches are also adjusted significantly lower than white key pitches. This indicates an enhanced uncertainty to black key pitches (or black key names) that may be due to the fact that the white key notes are the first notes learned when one starts playing music. Thus, the black key notes are learned subsequently and therefore may not be as fundamentally saved in memory as the white key notes (Miyazaki, 1990). Another explanation may be the greater exposure to white key notes in music in general, which has previously been shown to correlate with response time in a PIT (Simpson & Huron, 1994). The present result may have considerable implications for future AP studies in that results obtained by one method imply similar results obtained by the other method. However, the PAT method used here, have several advantages compared to a standard PIT. Instead of indirect measures of the IPT, we are able to directly measure the tuning and the stability of this tuning without having to extrapolate from indirect measures.

In conclusion, we show that pitch identification and pitch adjustment scores are correlated, yet a pitch adjustment test revealed further detailed information about the AP ability. Our findings suggest that musicians with AP tend to undershoot in a PAT compared to the concert standard pitch, and that this lower IPT tuning correlates with the number of weekly hours of actively played music. Furthermore, the APs adjusted the pitch closer to concert pitch standard in response to white key targets than to black key targets. We propose that frequent contact with the fixed chroma of an instrument updates the AP possessors' internal pitch template and keeps it "in tune." We furthermore speculate that APs' evaluation of white key notes compared to black key notes are more in tune, since they use them more while playing. However, to establish a causal relationship between playing and tuning, a future longitudinal study, using PAT of APs with a wider age range (e.g., from 5 to 90 years) and during periods of high and low musical activity, should be performed to thoroughly investigate the influence of musical activity on AP ability.

## Author Note

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