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Absolute Pitch May Not Be So Absolute

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Abstract

Most people cannot name the musical note that corresponds to a particular pitch without being provided a reference note, but those people with absolute pitch (AP) can do this accurately. Early experience during a developmental period is often thought to convey identity and stability of the note categories in people with AP, but the plasticity of these categories has not been investigated. Here we provide the first evidence that the note categories of adults with AP can change with listening experience. Participants with AP showed shifts in perception in direct accord with prior exposure to music detuned by a fraction of a semitone. This suggests that the apparent stability of AP categories is conferred not by early experience but rather by the cultural norms adopted for tuning music.

Keywords

music, auditory perception, perception

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Absolute pitch (AP) is generally defined as the perceptual ability to name musical notes without the aid of a reference note (e.g., Ward, 1999). A rare ability—occurring in approximately 1 out of 10,000 people in Western culture (Bachem, 1955; Takeuchi & Hulse, 1993)—AP has been idealized in popular culture as a rare and desirable musical endowment, partly because it has been assumed that several well-known composers (e.g., Mozart, Beethoven, Chopin, and Handel) possessed AP (Deutsch, 2002).

Despite years of empirical work, the mechanisms underlying AP are still not well understood. However, the general consensus is that once AP note categories are established in early life, they cannot be changed (Ward & Burns, 1982). This is not to say that there have been no reports of fluctuating pitch representations among people with AP. Such reports, however, have largely implicated low-level physical mechanisms, such as increased elasticity of the basilar membrane in the cochlea, which causes people with AP to hear everything as sharp as they age (Athos et al., 2007; Vernon, 1977; Ward, 1999). Certain drugs, such as carbamazepine, have also been found to shift pitch (usually downward) as a side effect (Chaloupka, Mitchell, & Muirhead, 1994; Kashihara, Imai, Shiro, & Shohmori, 1998; Kobayashi, Nisijima, Ehara, Otsuka, & Kato, 2001), although the underlying mechanism is not known. Finally, some research (e.g., Wynn, 1992) has suggested that pitch representations vary cyclically, in correspondence with hormonal fluctuations induced by sexual cycles in both men and women, though this claim has yet to be substantiated.

Nevertheless, the day-to-day note representations of persons with AP are remarkably stable, varying by about 0.05 semitones (5 cents) within a day (Wynn, 1972) and 0.33 semitones (33 cents) between days (Abraham, 1901, cited in Ward, 1963; Takeuchi & Hulse, 1993).[1] Yet it remains unclear whether this stability results from a frozen perceptual mapping established by early experience or a relative lack of variability in listening experience, given that most Western recorded music follows very specific cultural conventions for tuning, thereby restricting the range of experienced variability in pitch.

There is reason to suspect that the perceptual system does not directly and simply map physical frequencies to AP note categories. If there were such a direct mapping system, the only variability in note identification performance would arise from differences in peripheral auditory processes, but this is not the case. Although two people might both perform well enough on a note

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identification task to be considered to have AP, they can show significant differences in performance with specific timbres, notes, or frequency ranges that are not accounted for by differences in audiometry. Bahr, Christensen, and Bahr (2005) analyzed the accuracy profiles of several participants with AP and found that their timbre-, range-, and tonality-related differences in performance reflected individual experience, specifically, recent musical experiences, such as learning or studying an instrument.

Given these demonstrations that note categories of individuals with AP are affected by idiosyncratic experiences, we hypothesized that maintenance of AP categories may depend on a statistical distribution of experiences with particular notes and timbres, and thus may not reflect a direct neural mapping from cochlea to note category. If input sensitivity is not subject to a specific critical period during which note categories are crystallized (see Levitin & Rogers, 2005, for a review), then note categories in adults might be plastic, largely dependent on listening input. In the experiments reported here, we investigated whether brief, novel experience with out-of-tune musical categories affects musical note identification in people with AP. If exposure to out-of-tune pitches, in the context of a melodic form that maintains the relative tuning of notes, shifts note intonation judgments for individuals with AP, this suggests that the maintenance of putatively context-independent note categories may operate via the cultural conventions of tuning rather than some more fixed neural representation of frequency-note maps.

Experiment 1

It is said that if you want to boil a frog alive, you cannot simply drop the frog into boiling water because it will hop right out. Instead, you need to place the frog in cold water and raise the temperature in such small steps that the frog does not perceive a particular increase. That is the basic approach we took in the present study. When directly presented with out-of-tune music, listeners with AP will immediately detect that the music is not in tune. We therefore detuned music that participants listened to by a small amount, over time, in steps that were below the just-noticeable difference (JND) for pitch differences (e.g., Roederer, 1973). This allowed us to subtly change the perceptual experience of the listeners without their awareness.

Participants

Thirteen people (7 female, 6 male; mean age = 26 years, *SD* = 11 years) with AP participated in this experiment. All participants self-reported that they had AP, and an online test offered by the University of California, San Francisco (2012), verified that they had the highest level of absolute pitch (i.e., AP1; for specific details on AP1 classification, see Athos et al., 2007). Participants were paid for their participation in the experiment.

Task and procedure

The experiment consisted of three parts. The first was the prelistening session, in which participants heard both in-tune and out-of-tune notes within an octave range and made both labeling and intonation judgments. The test stimuli, which used a violin timbre, spanned from C4 (middle C) to B4 inclusive, in 33-cent increments. There were therefore three versions of each note category: a 33-cents-flat note, an in-tune note, and a 33-cents-sharp note. After hearing a note, participants were instructed to type in the name of the note (e.g., F#) and then to rank the intonation of the note on a scale from 1 to 3. A rating of 1 corresponded to an out-of-tune note, and a rating of 3 corresponded to a perfectly in-tune note.

The second part of the experiment consisted of listening to Johannes Brahms's Symphony No. 1 in C Minor. To ensure that participants were paying attention to the music, we instructed them to notate melodic themes, telling them that there was a possibility of a recall test later in the experiment. Although the symphony was initially presented in tune, over the course of the first movement (about 15 min), the pitch was slowly detuned at a rate of approximately 2 cents per minute, which is well below the JND for detecting pitch differences (Roederer, 1973). No participant reported any detection of the pitch shift when questioned after the experiment. The second, third, and fourth movements (approximately 30 min of music) were heard at a stable, detuned pitch, which was 33 cents below the starting pitch. To be clear, although we shifted the pitch of the music at a rate that was below the JND, the ultimate difference of 33 cents is well above most listeners' thresholds for detecting pitch differences (e.g., Hyde & Peretz, 2004).

After listening to the symphony, participants once again engaged in a note-labeling and intonation-judgment task. In this postlistening session, the stimuli were identical to those in the first part of the experiment, with the exception that a block of notes with piano timbre was added at the very end. Because the symphony did not use a piano, we included this block so that if there were a note-category shift, we could assess whether it generalized across timbres.

Results

Intonation judgments. To measure the effect of listening to the detuned music, we compared intonation judgments before and after the listening experience. If listeners' musical note categories are constantly tuned by their listening experience (i.e., if their categories are biased by the localized statistics of listening), then hearing a flattened piece of music should shift their note categories in a flattened direction (i.e., an assimilative effect). This would mean that participants would rate flat versions of notes higher (i.e., more in tune) than in-tune and sharp notes after listening to the detuned music.

To test this hypothesis, we compared intonation judgments in the pre- and postlistening sessions. Flat notes were heard as more in tune in the postlistening session (M = 2.31, SE = 0.11) than in the prelistening session (M = 2.08, SE = 0.08); in-tune notes sounded less in tune in the postlistening session (M = 2.16, SE = 0.10) than in the prelistening session (M = 2.28, SE = 0.12); and sharp notes sounded about the same in the postlistening session (M = 1.80, SE = 0.10) as in the prelistening session (M = 1.81, SE = 0.10). Thus, listening to detuned music significantly shifted the perceived intonation of 33-cents-flat and in-tune versions of notes, in an assimilative manner, and the Session × Note Type interaction was significant, $F(2, 24) = 6.57$, $p < .01$, $\eta_p^2 = .35$. Figure 1 highlights this significant interaction.

To test whether the effect of exposure to the detuned music changed over the course of the postlistening session, we divided the trials in that session into four segments in time. An analysis of variance (ANOVA) on the intonation judgments revealed that the interaction of note category and session segment was not significant, $F(3, 36) = 1.49$, $p > .20$, suggesting that the perceptual influence of the detuned music was stable throughout testing.

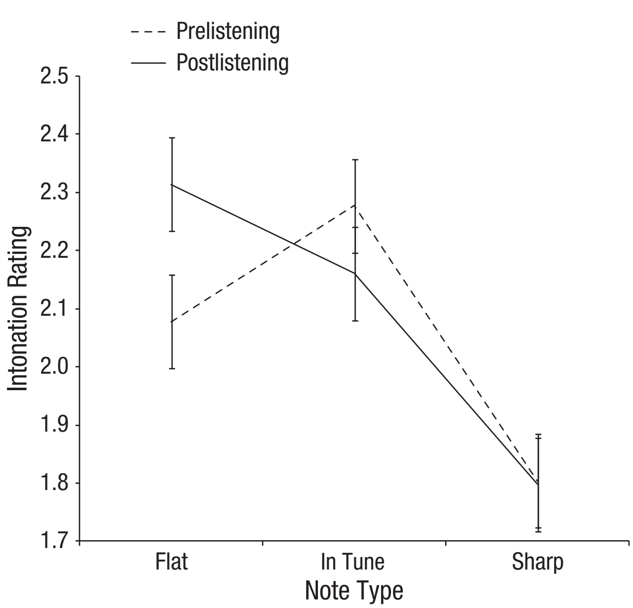

Fig. 1. Mean intonation ratings in Experiment 1 as a function of note type (flat, in tune, or sharp) and session (prelistening or postlistening). Error bars represent standard errors of the mean.

We did not observe a significant main effect of session (pre- vs. postlistening), $F(1, 12) = 1.42$, $p > .25$, which suggests that participants did not rate notes as overall more or less in tune after listening to the detuned music. However, we did find a main effect of note type, $F(2, 24) = 11.32$, $p < .001$, $\eta_p^2 = .49$, with sharp notes being rated as significantly less in tune (M = 1.80, SE = 0.10) than both flat notes (M = 2.20, SE = 0.09) and in-tune notes (M = 2.22, SE = 0.10). This finding, however, is not surprising given our experimental paradigm. Specifically, because flat notes and in-tune notes essentially switched places in the postlistening session, it makes sense that their means would be roughly equal, and also higher than the mean for sharp notes, which were consistently rated as out of tune in both the prelistening and the postlistening session.

Generalizability across timbres. As already mentioned, to test whether the perceptual shift generalized to other instruments, we included a block of trials with piano notes in the postlistening session. The Note Type × Instrument interaction was significant, $F(1, 12) = 5.67$, $p = .03$. Intonation judgments on the trials with piano notes were significantly different from those on the trials with violin notes and showed the prelistening judgment pattern, with in-tune notes being rated as more in tune than flat and sharp notes (flat notes: M = 2.08, SE = 0.12; in-tune notes: M = 2.27, SE = 0.15; sharp notes: M = 1.73, SE = 0.14). Thus, the judgments for piano notes did not indicate that there was an assimilative context effect on note categorization.

Discussion

Although listeners with AP can absolutely determine the note identity of a pitch without a reference note, this is not a fixed and immutable ability. In particular, listening experience seems to be able to rapidly change the mental representations of musical notes. This is the first empirical evidence that adults with AP shift their note intonation judgments in the direction of briefly experienced out-of-tune music. The present results suggest that although note representations may initially be established by early experience, cultural conventions of tuning standards are likely necessary to hold these representations in place. If each musical experience used something other than the "A = 440 Hz" standard, AP note representations might change constantly. Moreover, the failure of listening experience to shift note representations in the case of timbres that were not experienced as detuned suggests that note representations may be grounded in specific instrumental experience.

Experiment 2

Given the results from Experiment 1, we sought to determine whether experience with a limited number of notes produces category shifts that are specific to the experienced notes, or whether exposure to an altered subset of notes results in a generalization process whereby all notes shift categorically. Given the theoretic assumption that notes are not represented separately and independently but are connected in a culturally specified hierarchical organization (e.g., Krumhansl, 1979), changing one set of notes should modify the entire structure, especially if the set of notes implies a specific tonal area (key).

We also further tested timbre generalization by including an additional block of notes with a French horn timbre. The reason for including this timbre is that the tuning mechanisms of a French horn are much more fluid than the tuning mechanisms of a piano. In order to flatten or sharpen a French horn, one may adjust the tuning slides of the instrument, or even the degree to which the right hand is placed inside the bell. Thus, participants may be more willing to accept tuning variations on the French horn because they have experienced French horn tuning variability outside of the lab.

Participants

Fourteen people (8 female, 6 male; mean age = 24 years, *SD* = 7 years) with AP participated in the study. Participants met the criterion for AP1 performance on the online test used in Experiment 1 and were paid for their participation in the experiment.

Task and procedure

The experimental design was similar to that used in Experiment 1. There were three parts to the experiment. In the first and third parts (prelistening and postlistening sessions), participants performed the note-labeling and intonation-judgment task, with a block of French horn notes substituting for the block of piano notes in the postlistening session. In the second part, they listened to detuned (33-cents-flat) musical pieces.

The main difference between Experiment 1 and Experiment 2 was in the musical pieces used in the second part of the experiment. Specifically, in Experiment 2, we used four pieces of phase music. Phase music is characterized by identical melodic patterns that are played simultaneously at slightly different tempos, which results in intricate, complex musical pieces that consist of a limited number of pitches. Indeed, the four musical pieces in Experiment 2 only used five notes: G, A, B♭, C, and D. (For an example of the phase music used in the experiment, please refer to Phase Music Sample in the Supplemental Material available online.) Thus, we could assess whether the listening context affected only these five notes that were detuned during the listening experience, or whether the effect of this listening experience generalized to all notes within the octave of these five notes.

As in Experiment 1, we slowly detuned the pitch of the first 15 min of music (the first piece of phase music) until the pitch was flattened by 33 cents. The subsequent pieces were heard at this detuned pitch (for ~45 min). To ensure that participants were attending to the pieces, we asked them to notate the main melodic figure from each piece. Participants were thus led to believe that this portion of the task was about AP and musical phrase perception. No participants commented on the detuned nature of the pieces.

Results

Intonation judgments. To test whether exposure to the detuned musical pieces affected note perception only for the notes heard in those pieces (G, A, B♭, C, and D), we analyzed the intonation judgments in a repeated measures ANOVA with session (pre- or postlistening), note type (flat, in tune, or sharp), and note group (heard or unheard in the detuned music) as repeated factors. Intonation judgments were significantly affected by exposure to the detuned music, as demonstrated by a significant Session × Note Type interaction, $F(2, 26) = 7.87$, $p < .01$, $\eta_p^2 = .25$. Thus, 33-cents-flat notes, which participants judged out of tune prior to listening to detuned music (heard notes: $M = 2.13$, $SE = 0.08$; unheard notes: $M = 2.12$, $SE = 0.07$), were judged as significantly more in tune after participants listened to the music (heard notes: $M = 2.41$, $SE = 0.07$; unheard notes: $M = 2.23$, $SE = 0.07$), and in-tune notes were rated as more out of tune after participants heard the music (heard notes: $M = 2.17$, $SE = 0.06$; unheard notes: $M = 2.11$, $SE = 0.09$) than before (heard notes: $M = 2.34$, $SE = 0.09$; unheard notes: $M = 2.29$, $SE = 0.08$). These results show that listening to detuned music changes perception of both heard and unheard notes, demonstrating generalization across the scale for the detuned instrument.

It is possible, however, that the notes heard in the detuned music drove this interaction. If this were the case, there would have been a significant three-way interaction, indicating that the Session × Note Type interaction differed significantly between notes that were and were not experienced as detuned. However, we failed to find a significant three-way interaction, $F(2, 26) = 0.54$, $p = .59$. This suggests that the flat versions of all notes were judged as the most in tune following exposure to detuned music consisting of a limited subset of notes.

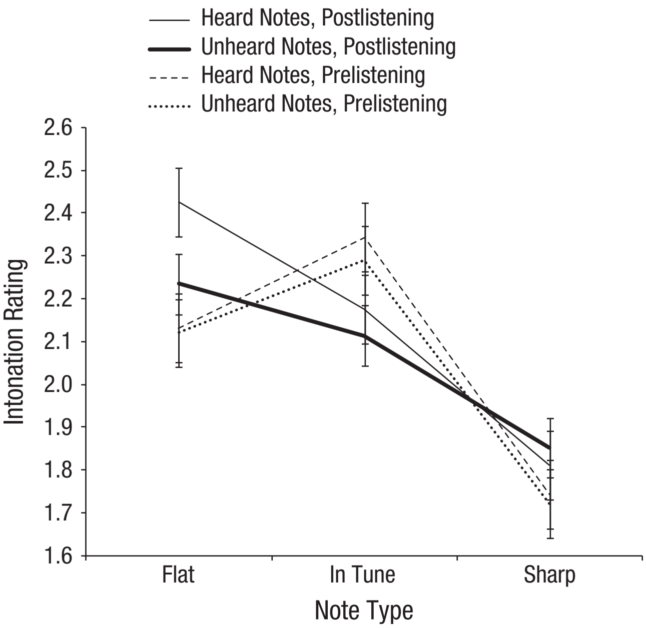

Fig. 2. Mean intonation ratings in Experiment 2 as a function of note type (flat, in tune, or sharp), session (prelistening or postlistening), and note group (heard or unheard in the detuned music). Error bars represent standard errors of the mean.

Figure 2 highlights the intonation judgments from Experiment 2.

As in Experiment 1, we did not observe a significant main effect of session, $F(1, 13) = 2.27$, $p > .15$, which suggests that participants did not rate notes as overall more or less in tune after listening to the detuned music. Also as in Experiment 1, we observed a significant main effect of note type, $F(2, 26) = 27.99$, $p < .001$, $\eta_p^2 = .67$, with sharp notes being rated as significantly less in tune (M = 1.80, SE = 0.06) than flat notes (M = 2.22, SE = 0.06) and in-tune notes (M = 2.23, SE = 0.06).

Generalizability across timbres. The final block of the experiment, which consisted of trials with flat, in-tune, and sharp notes played with a French horn timbre, was included so we could assess whether the shifted-category effect generalized to a novel timbre. A repeated measures ANOVA comparing intonation judgments for the violin and the French horn notes in the postlistening session revealed a significant Note Type × Instrument interaction, $F(2, 26) = 5.33$, $p = .01$. For the French horn, the intonation judgments were highest for in-tune notes (flat notes: M = 2.20, SE = 0.09; in-tune notes: M = 2.39, SE = 0.13; sharp notes: M = 2.04, SE = 0.12). Thus, despite the fact that the French horn has a much more fluid tuning system than the piano, the effects of listening to detuned music in the violin timbre also did not generalize to the French horn timbre. Figure 3 illustrates the lack of generalization across timbres in Experiments 1 and 2.

Discussion

Experiment 2 was designed to investigate both the note and the timbre generalizability of the assimilative context effect found in Experiment 1. Specific note and instrument experience provided in the detuned music generalized to unheard notes but not an unheard timbre. It remains unclear whether the effect might generalize between instruments that have similar acoustic properties yet distinguishable qualities as evidenced by multidimensional scaling (e.g., Iverson & Krumhansl, 1993). Taken together, the results of Experiment 2 suggest that altered listening experience is sufficient to shift note intonation judgments in the direction of the listening experience, as long as the timbres in the listening experience and the postlistening stimuli match, and that this shift applies to both notes that were heard and notes that were unheard in the altered music.

General Discussion

These experiments provide empirical evidence that even short-term listening experience can alter the representations of musical notes in people—including adults—with AP. Exposure to altered note exemplars, moreover, generalizes to other notes, but apparently not to different timbres.

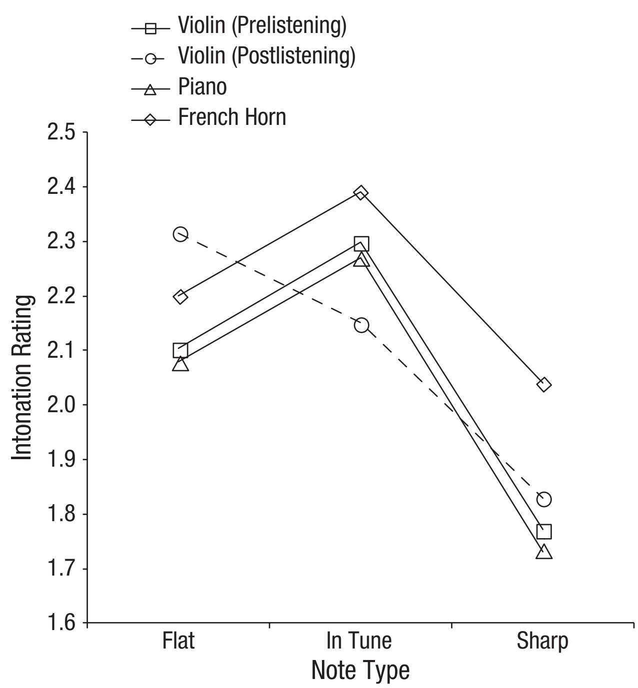

Fig. 3. Mean intonation ratings in Experiments 1 and 2 as a function of note type (flat, in tune, or sharp) and timbre (violin, piano, or French horn). Results for the violin timbre in the prelistening and postlistening sessions are aggregated across the experiments. Notes in the piano (Experiment 1) and French horn (Experiment 2) timbre were rated in the postlistening session only.

When exposed to detuned music for as little as 45 min, listeners with AP show significant changes in the tuning of their note categories. This demonstrates clearly that their note categories do not have fixed absolute frequency referents established at an early age. Instead, listeners with AP, even as adults, have note categories that are plastic. Our participants received very little listening exposure to the detuned music, in comparison with a lifetime (upward of 20 years) of listening prior to the experiment, which suggests that these categories are not simply mutable but highly sensitive to input. The fact that these changes in tuning can be induced with relatively little exposure suggests further that the tuning of note categories does not simply reflect the statistical distribution of experience (given how small a part of that experience the experiment represents) but instead reflects a great deal of immediate context sensitivity. It is notable that over the course of the postlistening session in Experiment 1 (which lasted about 45 min), there was no significant change in intonation judgments. Moreover, listening to perfectly in-tune notes during postlistening testing did not reset the effect of exposure to the detuned music. Although truly in-tune notes should be detected by any system dependent on absolute frequency and thus provide a basis for reestablishing the standard tuning of note categories, our results suggest that it is the perceived character of notes defined within a musical context—not absolute acoustic frequency—that is most important for establishing note tuning.

Recently, Wilson, Lusher, Martin, Rayner, and McLachlan (2012) proposed a model of AP acquisition and maintenance, stating that in addition to genetic factors and learning of tone-label mappings at an early age, environmental factors—such as learning pitch names on a fixed-do instrument—are crucial to AP acquisition, because tone-label mappings need to be consistent in order to reorganize the auditory cortex in a long-term fashion.[2] However, once these perceptual mappings have been established through mechanisms of associative learning (e.g., Bermudez & Zatorre, 2005; Bregman, 1990), it may be necessary to hold them in place through continued exposure to consistent tone-label mappings. The results of the present experiments thus support Wilson's model of AP category maintenance, for the disruption of consistent tone-label mappings (through the presentation of mistuned stimuli) temporarily shifted note intonation judgments in listeners with AP.

The results from Experiment 2 in particular demonstrate that the entire representation of the musical scale is linked in its mental representation. Experience with a subset of detuned notes in music affects perception of all the notes in the scale. This suggests that the change in tuning resulting from detuned listening experience goes beyond the notes that are heard. But there are limits to this generalization in that the effect of exposure to detuned music is limited to the instrument that was heard. This suggests that although musical notes from the scale are connected in mental tuning, different timbres are not, as if each instrument voice maintains its own separate tuning. Indeed, the phenomenon of *absolute piano* (e.g., Ward & Burns, 1982), the ability to pass AP tests only if the notes have a piano timbre, provides a striking example of how timbres can be separately maintained. The present results thus build on the notion that AP note representations are, to some extent, based on the timbre in which notes are presented, as experience with mistuned stimuli affects categorization only of notes sharing the same timbre.

Overall, we have provided evidence that the note categories of listeners with AP are not frozen with specific frequency values early in life and immutable thereafter. Instead, our results demonstrate that such note tunings remain plastic even for adults. The fact that individual in-tune notes experienced following exposure to mistuned music do not shift tuning back suggests that listeners with AP use the relative values of notes in a melody to determine the tuning of their note categories, even for notes not heard in the melody. Thus, although note judgments of listeners with AP may be accurate in the absence of a reference note, the tuning of their note categories appears to depend on the relative pitch changes in music they have listened to. This means that the perceptual ability that is currently termed AP depends on cultural conventions of music (i.e., the common standard for tuning), because the mental tuning of the note categories depends on day-to-day listening experience.

Author Contributions

S. C. Hedger developed the paradigm, coded the data and wrote the computer script, ran participants, analyzed data, and wrote the manuscript. S. L. M. Heald analyzed data and edited the manuscript. H. C. Nusbaum, analyzed data and edited the manuscript.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Notes

1. A cent is a logarithmic unit of measurement equivalent to 1/100 of a semitone, the smallest distance between two notes using Western notation (e.g., C to C#).
2. Fixed-do instruments emphasize a fixed, categorical pitch (e.g., piano, organ), whereas movable-do instruments have a variable categorical pitch (e.g., brass, woodwinds, strings, voice).

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