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INVITED REVIEW

How well do we understand absolute pitch?

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Abstract: Absolute pitch (AP) is the ability based on the fixed association between musical pitch and its verbal label. Experiments on AP identification demonstrated extreme accuracy of AP listeners in identifying pitch, influences of timbre and pitch range, and difference in accuracy between white-key notes and black-key notes. However, contrary to the common belief that AP is a component of musical ability, it was found that AP listeners have difficulty in perceiving pitch relations in different pitch contexts, and in recognizing transposed melodies, as compared to listeners having no AP. These results suggest that AP is irrelevant and even disadvantageous to music. Systematic music training in early childhood seems effective for acquiring AP. Possible genetic contributions to AP are undeniable, but evidence for them is inconclusive. There are several AP-like phenomena that do not reach consciousness: absolute tonality, long-term memory of pitch of repeatedly heard tunes, specific patterns of pitch comparison in the tritone paradox, and fixed pitch levels in speech. Contrary to true AP observed as a pitch naming ability, the implicit AP phenomena are widespread among general population.

Keywords: Absolute pitch, Relative pitch, Early learning, Tonality, Pitch naming

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1. THE DEFINITION OF ABSOLUTE PITCH

The term "absolute pitch" (hereafter AP) is usually used to refer to having good ears in the very vague sense of the term. Attention has been often devoted to such idiosyncratic features of AP that people having AP are able to identify the note names of nonmusical sounds like clinks of glasses or ambulance sirens. Despite a great deal of attention to AP, our understanding of AP mainly comes from anecdotal reports and is far from accurate. The purpose of the present paper is to present an accurate description of AP with its empirical evidence.

AP is defined as an ability to identify the pitch of isolated tones using musical pitch labels (passive AP) or to produce the pitch of any tones designated by note names (active AP) without comparing with any reference pitch [1,2]. Some other AP-like phenomena have been reported, broadening the definition of AP, such as, for example, long-term pitch memory of familiarized musical pieces [3,4], absolute key identification [5], or pitch stability of speech demonstrated by the native speakers of some tone languages [6]. However, it is not clear how these phenomena are related to AP in a narrow sense. Hence, it seems safe, at present, to regard AP as the ability to identify the categories of musical pitch. Sometimes, the term "perfect pitch" is used as a synonym for AP. However, this term is misleading, because, as described later, AP is no perfect in musical sense.

2. PERCEPTION OF ABSOLUTE PITCH

The first scientific description about AP in literature appeared in Stumpf's *Tonpsychologie* [7]. Since then, a number of studies have addressed this issue [8–15]. However, most of the early studies primarily focused on an aspect of AP as a rare ability or attempted to demonstrate its learnability from the standpoint of the nature-nurture controversy. Apparently, there has been little attempt to study AP from the psychophysical or cognitive viewpoint. Then, I conducted a series of experiments to investigate how people having AP perceive musical pitch.

First of all, the accuracy of AP identification was investigated in an experiment in which 84 chromatic scale tones ranging from C1 (32.7 Hz) to B7 (3971.1 Hz) were presented [16]. Participants tried to identify the musical pitch name by pressing a corresponding key on the musical keyboard as quickly as possible. The response accuracy and the response time were measured. The results showed that the AP listeners were exceptionally accurate in identifying pitch names within an octave, but were prone to octave errors (correct in pitch naming but incorrect in octave placement). It is not pitch height (octave placement) but pitch class (musical characteristics of a scale tone within an octave) that AP listeners perceive directly. It is assumed that AP listeners adopt the two-stage process in which they identify pitch class of the presented tone and then locate its octave position. By contrast, people having no AP are insensitive to pitch class but are able to classify tones into rough pitch categories in terms of timbral characteristics correlated with positions in the frequency continuum. AP listeners and non-AP listeners seem to be equivalent in accuracy in identifying pitch height.

The accuracy of AP identification is dependent on the timbre of the tones to be identified. In an experiment in which grand-piano tones, synthesized piano-like tones, and sinuoidal tones are presented as test tones [17], identification performance was most accurate for the grand-piano tones (overall percentage correct, 94.9%), least accurate for sinusoidal tones (74.4%), and intermediate for the synthesized-piano tones (84.3%). Pitch regions also influenced the accuracy of AP identification; the accuracy was the highest for tones of the central octave region (C4-B4), but was lower for tones more distant from the central region (the decrement in accuracy was more noticeable in the lower frequency region than in the higher region).

Another important finding was the difference in accuracy of AP identification among pitch classes [17,18]. Generally, tones corresponding to the black keys on the piano keyboard (notes with an accidental in musical notation) were more often misidentified than white-key notes (without an accidental). There were considerable differences in AP accuracy among AP listeners. The difference between accurate AP listeners and inaccurate AP listeners was considerably large for black-key notes, but not for white-key notes. Response times for different pitch classes were inversely related to the response accuracy; response times were faster to white-key notes that were identified more correctly, but were slower to black-key notes that were identified less accurately. Similar findings were also reported by other researchers [19]. Comparing among the AP listeners, the accurate AP listeners were fastest in responding (605 ms in average), the inaccurate AP listeners were slowest (1,167 ms), and the moderately accurate AP listeners were intermediate (717 ms). Very rapid responding is a characteristic of accurate AP listeners. It may therefore be possible to differentiate true AP from pseudo-AP that relies on relative pitch on the basis of response times.

Inaccurate AP listeners made a lot of errors, which displayed an asymmetric confusion pattern between whitekey notes and black-key notes; black-key notes were more often confused with neighboring white-key notes than vice versa. Some inaccurate AP listeners had AP for white-key notes but not for black-key notes. This type of AP may be called “partial AP” or “white-key note AP.” Probably, inaccurate AP listeners have not well established AP for black-key notes, and consequently often make such errors as judging black-key tones as adjacent white-key tones. The partial AP for white-key notes may be attributed to the acquisition process of AP during early childhood. As described later, the most of AP listeners are assumed to have acquired AP through early musical training (mainly in piano playing), in which AP for white-key notes is more likely to be established than black-key notes. The piano lesson almost always begins with playing scales and pieces in the C major, and consequently children are exposed more often to white-key tones, but not to black-key tones in the early phase of musical training. The period of early childhood (about 3 to 6 years of age) is assumed to be a sensitive period for acquiring AP, in which AP is most effectively acquired. The sensitive period may sometimes expire when black-key notes are introduced in the later phase of musical training [1]. As a consequence, possessors of partial AP are produced, who have established AP for white-key notes, but not for black-key notes.

3. ABSOLUTE PITCH AND RELATIVE PITCH

The musical pitch system is not absolute in nature. Most important musical aspects such as melody and harmony are constructed on pitch relations. Most musicians even without AP are able to perceive the pitch relations, and so have no difficulty in engaging in musical activities. They are able to perceive musical pitch with reference to the cognitive schema (tonal context), which is established on the basis of musical pitch relations given a reference pitch [20,21]. Musically indispensable is the ability to perceive the pitch relationship (relative pitch, hereafter RP) in the musical pitch context such as musical scales and tonality.

AP has long been considered to be a remarkable component of musical talent. It is indeed a special ability, but it should be noted that it is special because the AP possessor absolutely internalizes musical pitch that should be perceived by nature relatively in a musical pitch context. People having excellent RP, although having no AP, are able to shift a pitch framework freely at any pitch level within the musical pitch range. Such relativity is an essential characteristic of musical pitch. Compared to RP, AP may be irrelevant and dispensable to music.

If AP is merely irrelevant to music, it could be simply ignored. However, AP and RP are actually very different modes of musical pitch processing, having incompatible features, and therefore it may be possible that one can interfere the development of the other, and vice versa. As interference in one direction, the development of RP may make it difficult to acquire of AP. The balance shift from AP to RP during childhood is, supposedly, consistent with a general feature in cognitive development of children

[22]. RP begins to develop at about 6 years old when children become gradually efficient in perceiving musical pitch on a relational base rather than an absolute base. This balance shift toward RP, in turn, may make AP acquisition more and more difficult, because RP processing should override the fixed associations between pitch and a pitch label.

What about then interference in the reverse direction, i.e., from AP to RP? In cases where children once have acquired AP through appropriate training for AP during early years, their musical activities may tend to be dependent on their AP ability, and sometimes their motivation to learn RP may diminish. As a consequence, AP acquired in early childhood may in turn make it more or less difficult for the children to develop RP. If this were the case, AP would mean no admirable ability at all, but rather represent a hindrance to development of the musically important skill, resulting in a sort of handicap for musicianship.

4. PERCEPTION OF MUSICAL INTERVALS BY AP POSSESSORS

The above speculation that AP may be a musical handicap leads to a challenging hypothesis that AP listeners have difficulty in transposing musical pitch patterns to any pitch level. This hypothesis was tested at first in several experiments on perception of musical intervals [23,24].

In every trial, participants heard an ascending musical interval preceded by an authentic cadence (a chord sequence of V7-I) that was for the purpose of establishing a particular tonal context (tonality). The preceding chord sequence implied one of three tonalities: major keys with C, F#, and a quartertone lowered E as a tonic. The first tone of the following pair of tones always corresponded to the tonic (*do*) of the key implied by the preceding cadence; the pitch interval between the two tones varied from 260 to 540 cents at intervals of 20 cents; i.e., the second tone ranged from slightly lower *mi*^{b} to slightly higher *fa*. Participants listened to the pair of tones in the key context established by the preceding cadential chords and tried to determine whether the last tone was *mi*^{b}, *mi*, or *fa* relative to the first tone as *do*. Although a number of the stimuli to be identified were out-of-tune intervals, it was not so difficult to classify them into the designated interval categories because musical intervals are known to be perceived categorically [25].

Participants having AP showed significantly degraded performance in the F$^{\#}$ major and the out-of-tune E major contexts compared with the C major context, whereas participants having no AP exhibited an equally high level of accuracy regardless of the key contexts. In the C major context, the AP listeners and non-AP listeners were nearly equal in performance, but, in the other contexts, the AP listeners were significantly poorer than the non-AP listeners. There were actually large individual differences among AP listeners in accuracy of identification in the non-C contexts. Approximately half of the AP listeners showed a substantial decrement in performance in the non-C contexts relative to the C context, while some of the AP listeners identified accurately regardless of the key contexts. In contrast, all of the non-AP listeners performed equally well regardless of the key contexts. This result indicates that AP listeners tend to adhere to an inappropriate strategy to rely on AP even when confronted with the task that requires to use RP. Contrary to the popular opinion about AP that a good AP listener ought to have good RP, AP and RP are sometimes incompatible and AP may be a hindrance to RP.

5. PERCEPTION OF MELODIES BY AP POSSESSORS

Given that AP listeners tend to rely on AP in musical activities and have difficulty in perceiving RP, they may also have disadvantages in perceiving transposed melodies. To examine this possibility, melody recognition experiments were carried out [26,27].

In an experiment which used a transposed-melody recognition task [26], participants listened to a brief standard melody and a comparison melody successively. The standard melody was always played in the C major mode, and the comparison melody was played in the C major key (the untransposed condition) or in the key of F$^{\#}$ major or a slightly shifted major key with a quarter-tonelower E as a tonic (the transposed condition). The comparison melody was either the same or different from the standard; the same comparison melody was identical to the standard with respect to pitch relations; the different comparison melody included one component tone shifted one step upward or downward on the diatonic scale, with the restriction that the melodic contour was preserved in spite of this change. Participants attempted to decide whether the two melodies were identical or not without regard to changes in AP.

Both the AP and non-AP groups exhibited the nearly perfect level of performance in the untransposed condition where the standard and the comparison melodies could be compared at the same pitch level and hence all that the listener had to do was to detect a different pitch between the two melodies. In contrast, in the transposed condition (the F$^{\#}$ and lower E key contexts), both groups showed a decline in performance, with a larger decrement exhibited by the AP group than the non-AP group. To compare melodies in different key contexts, listeners have to use pitch relations. Thus, a substantial performance decrement the AP group exhibited indicates that AP listeners have difficulty in perceiving pitch relations.

In another experiment, a similar task of melody recognition was administered to listeners, except that the standard melody was displayed visually in a format of the musical score. The standard melody was always notated in the C major key, and the comparison melody was presented auditorily with a preceding cadential chord sequence (V7-I) for establishing a certain tonality. There were three tonality conditions for the comparison melody; the C major (the matched key condition), the $F^{\#}$ major, and the lower E major (the unmatched key conditions). As before, the comparison melody was either identical or not to the notated standard with respect to relative pitch.

The non-AP listeners performed equally well regardless of the key conditions, as expected from the general principle of equivalence of melodies under transposition. In contrast, the AP listeners achieved a highly superior performance in the matched key condition, but showed lower performance in the unmatched key conditions. The AP group was superior to the non-AP group in the matched key condition with the benefit of AP, but conversely the non-AP group excelled in the unmatched key conditions with the benefit of RP. The same reversal in performance between the AP listeners and the non-AP listeners was observed in additional experiments with music students with more extensive training in Poland [27]. These results of the melody recognition experiments, together with those of the interval identification experiments, provide converging evidence that AP may be a disadvantage for musicianship.

6. AN AUDITORY STROOP PHENOMENON — COGNITIVE INTERFERENCE BETWEEN PITCH AND PITCH LABELS

People having AP use a fixed pitch-naming method in naming musical pitch, in which each musical pitch is associated with a pitch label, usually a solfege syllable (*do*, *re*, or *mi*, etc.) designating notes in the musical scale, in a fixed manner that *do* always represents the pitch of C; hence this method is called the "fixed-*do*" system in solfege. In contrast, RP corresponds to the "movable-*do*" system, in which each pitch syllable is assigned flexibly to a pitch in a musical interval or a melody depending on the key context in which it is placed. While the fixed-*do* and movable-*do* methods originally represent different pitchnaming methods in solfege singing practice, they also represent different pitch recognition modes of AP and RP. For AP possessors, a task of recognizing musical intervals or melodies in different pitch contexts requires to call pitches that have fixed names as different names depending on the pitch context given. This situation is assumed to produce a cognitive conflict, resulting in performance declines as observed.

This type of conflict and the resultant interference is similar to the Stroop phenomenon that was first demonstrated in the visual domain by Stroop [28]. The classical Stroop phenomenon is typically a cognitive interference that occurs in naming the ink color of the printed color word when the ink color is incongruent with the color designated by the word, usually resulting in longer response times than when naming the color of a color patch [29]. In contrast, almost no interference occurs when reading a word without regard to its printed color even if the ink color is incongruent to the color the word means (the reverse Stroop effect). An auditory analogue of the visual Stroop phenomenon is expected to occur in the auditory domain between pitch and pitch names.

In an experiment to examine this possibility [30], participants heard vocal tones that were matched in pitch to the tones of the C major scale. They were sung by a trained singer with different pitch syllables. The pitch and the syllable were either congruent according to the fixed-*do* pitch naming system (e.g., a "*do*" syllable was sung in pitch of C) or incongruent (e.g., a "*do*" syllable was sung in pitch of D). The participants were asked to name pitch of each tone without regard to the articulated syllable (the pitch task), or to repeat the syllable disregarding to the pitch of the tone (the syllable task). The participants were encouraged to respond as quickly as possible, because response time was the primary measure of the interference effect.

In the pitch task, both the AP and non-AP listeners responded significantly slower when pitch and syllables were incongruent than when they were congruent. This is consistent with the Stroop interference typically observed between color and color names. In the syllable task, on the other hand, the non-AP listeners responded equally fast in both the congruent and incongruent conditions; that is, no reverse Stroop effect was obtained. However, more importantly, the AP listeners did show the reverse Stroop effect; that is, response times were significantly longer to the incongruent stimuli than to the congruent stimuli. This appears to be curious when considering that repeating immediately a heard syllable (shadowing) is an example of a special class of input/output transformations called "privileged loops" [31]. Nevertheless, the AP listeners' results showed that the privileged shadowing suffered interference from associations of pitch and its name. This suggests that conversion from pitch to its name is a highly automatized process for AP listeners.

7. THE ORIGIN OF AP

There has been a continuing controversy about the origin of AP, mainly between theories that emphasize hereditary-genetic contributions to AP and theories that stress learning contributions [1,2]. Proponents of the genetic theories emphasize the extreme rarity of AP among general population, and argue that, nevertheless, AP highly aggregates in families [32–36]. Indeed, the proportion of AP possessors is said to be less than 0.01%, as frequently quoted [1,33,35,37]. However, this is an unreliable estimate without any empirical evidence and is likely to be cited to overstate the rarity of AP. Furthermore, the proposed evidence for the genetic view is inconclusive. Usually, the genetic factors and the environmental factors are inseparably confounded, and the high incidence of the AP phenotype alone is not reliable evidence for the contribution of the genetic factors [38,39].

On the other hand, there have been a number of attempts to examine whether AP is acquired through training. Some of those attempts demonstrated that it is possible to memorize a fixed standard pitch to some extent [40–42]. However, these effects of training AP are far from the level of true AP possessors who can immediately and accurately identify 12 pitch classes within one octave. Thus, there has been not yet conclusive evidence supporting the learning theories of AP.

Particularly noteworthy in this regard is a higher prevalence of AP possessors in present-day Japan, which is in marked contrast to the extreme rarity of AP possessors in Europe and North America. A tentative estimate from the results of AP test I accumulated so far suggests that, in Japan, the proportion of AP possessors is approximately 30% for university students of music education and 50% or more for music students. Such a higher prevalence of AP in Japan is assumed to result from the prevailing practice of giving children music lesson mainly in piano playing from early childhood. There are schools that provide younger children with training for the purpose of developing AP. It is sometimes informally reported that generally the later the age of commencement of training is, the more difficult AP acquisition is. In fact, almost all the AP participants I observed so far began musical training in private music schools at the age from 3 to 6 years. Moreover, questionnaire surveys of a large number of musicians indicated that the proportion of respondents who reported having AP decreased monotonically as the age of commencement of musical training increased [36,43]. Taken together, these results support the early-learning view of AP, proposing that AP is most effectively acquired by some sort of training in early childhood. The early-learning view of AP parallels with the critical period hypothesis for language development, suggesting that the acquisition process of AP should be considered within a broader framework of cognitive development in general.

However, existing evidence for the early-learning model of AP is largely indirect such as anecdotal reports or surveys based on biographical recollections. There has been yet no compelling evidence supporting directly the model. Indeed, some researchers provided children with training for AP, but failed to obtain positive evidence [44,45]. These failures may be, in part at least, due to a limited amount and period of training given. Then, we tested children of 4 to 10 years old who attended to music schools to figure out the developmental process of AP [46]. It was found that the accuracy of AP identification increased to a level of 80% correct or more between 4 and 7 years old, and more than 2/3 children acquired accurate AP of an accuracy level of 90% correct or more. It was also found that AP for black-key notes developed later than AP for white-key notes. These results indicate that AP is acquired with considerable reliability through a long-term training in childhood.

On the other hand, recent experiments reported results indicating that prelinguistic infants are able to carry out the learning task that requires processing of AP, suggesting the genetic basis for AP [47,48]. However, the AP processing the infants exhibited in these experiments reflects a primitive type of AP and, obviously, later systematic training is needed to develop true AP. The genetic basis of AP, if any, may not be limited to rare cases but would be a prevailing predisposition for developing AP.

8. AP-LIKE PHENOMENON — IMPLICIT AP

While the type of AP described above is the ability to identify musical pitch by using pitch labels, several AP-like phenomena without explicit pitch naming have been reported.

For AP possessors, it should be fairly straightforward to identify the tonality of a tune heard by identifying its tonic. It was found that non-AP possessors were also able to recognize, though somewhat inaccurate, the absolute pitch level at which the tune was played. Terhardt [5,49] presented participants with excerpts of J. S. Bach's twelve preludes of *Well-Tempered Clavier* in the original key and variously transposed keys, and asked them whether the piece was played in the proper key (key identity was not required). AP listeners were obviously very accurate in this task, and non-AP listeners were also able to judge the proper key with a moderate degree of accuracy. This result indicates that non-AP listeners as well as AP listeners use AP information when identifying tonality. However, AP listeners and non-AP listeners supposedly used different strategies in performing this task. AP listeners performed the task explicitly by identifying the tonic note of the excerpt, while non-AP listeners did it implicitly probably by relying on an intangible key feeling.

Another line of research pursued implicit AP in experiments that asked participants to produce pitch of familiar tunes. When participants having no AP sang a beginning pitch of a familiar song, the pitches reproduced at different occasions well coincided [50]. Another experiment indicated that more than 60% of non-AP participants reproduced an initial pitch of a familiar song within 2 semitones of the pitch of the original recording [3]. Furthermore, in an experiment that used sound-tracks of familiar television programs, participants with no musical training successfully distinguished the correct version played at the original pitch level from the incorrect version shifted upward or downward by 1 or 2 semitones [4]. These results suggest that with repeated exposures to a tune played at the fixed pitch level, we establish the long-term memory of the tune, a component of which holds the AP information of the tune.

Hence, while the ability to name the musical pitch of individual tones is AP in the narrow sense, and those with this ability deserve true AP possessors, others with no such ability seem to retain AP information of sounded tunes to some extent. However, the latter type of AP usually does not arrive in conscious awareness, and is less accurate than the explicit true AP.

The tritone paradox reported by Deutsch [51,52] seems to be another example of the implicit AP. With the Shepard tones that perceptually repeat at an octave interval, two tones at an tritone interval are ambiguous in pitch height, and consequently ought to have a fifty-fifty chance whether they sound ascending or descending [53]. However, pitch judgments actually depended on pitch classes of the two tones to be judged, and each individual listener exhibited a specific pattern of pitch judgment, which tended to be related to the individual's language backgrounds [54]. Furthermore, she noticed the stability and consistency of pitch of speech by native speakers of tone languages such as Mandarin, Thai, and Vietnamese, and suggested a possible association between the implicit type of AP and the process of language acquisition [55]. These AP-like phenomena suggest the possibility that people without true AP retain AP information at an unaware level, and this type of implicit AP is widespread among the general population.

9. CONCLUSION

True AP is the ability based on the fixed association between musical pitch and its verbal label and necessitates musical training. However, contrary to the common belief, it is not necessarily musical in nature, but is completely different from genuine musical ability for musical intervals, melodies, harmony, and tonality. AP may even be incompatible with RP that is essential for music. To develop AP as an ability to identify musical pitch, obviously, some sort of musical training is necessary; particularly, training in an early age seems effective for acquiring AP. Possible genetic contributions to AP are undeniable, but evidence for them is inconclusive. In contrast to true AP that is consciously experienced, there are several AP-like phenomena that do not reach consciousness. These are indirectly observed AP phenomena that include absolute tonality, long-term memory of pitch of repeatedly heard tunes, specific patterns of pitch comparison in the tritone paradox, and fixed pitch levels in speech. These phenomena of implicit AP are widespread among general population, contrary to true AP observed in only trained people. It is not yet clear how explicit AP and implicit AP are related.

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