# Is Absolute Pitch Learnable? Implicit and Explicit Absolute Pitch

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## Abstract

Absolute pitch (AP) is the ability to identify and name an isolated tone by ear. The review begins with a brief overview of AP and the seeming bizarreness of its rarity. I then consider some reasons why AP learning may be inherently more difficult than typically assumed. First, the simplicity of what needs to be learned could be overstated if not taking into consideration the diversity of auditory stimuli (e.g., varying in timbre and octave) within each pitch class. A further reason for the rarity of AP could simply be the lack of extensive appropriate training. I then discuss implicit AP, which seems to be possessed by most, even non-musicians. Implicit AP refers to the ability to identify pitches absolutely at a more unconscious level but the inability to verbally label them. The review then considers growing evidence against the notion that AP is essentially unlearnable without the right genetic endowments and/or early music education. Procedures that might inhibit or facilitate AP learning are discussed. Incidental (i.e., non-intentional) learning may be particularly effective in training this difficult-to-acquire skill. A new multifactorial perspective of AP acquisition is presented along with some open questions for future research.


**Keywords:** absolute pitch, perfect pitch, explicit learning, implicit learning, incidental learning

*Absolute pitch* (AP) or *perfect pitch* is the ability to name isolated tones by ear, without the aid of an initial reference tone of known pitch (for reviews, see Bachem, 1955; Deutsch, 2013; Di Stefano & Spence, 2024; Levitin & Rogers, 2005; Loui, 2016; Moulton, 2014; Takeuchi & Hulse, 1993; Ward, 1999). For instance, if I were to play a random note (e.g., on the piano), then an *AP possessor* would be able to identify and name the note (e.g., do♯ in fixed-do solfège or C♯ in the letter notation common in English-language speaking countries).[1] Accuracy might not be perfect, but will tend to be very high for an AP possessor (with errors typically being only slight misses; i.e., semitone errors) and pitch identification is typically very rapid and automatic (Bermudez & Zatorre, 2009; Miyazaki, 1988, 1990; van Hedger et al., 2019; Wong, Lui, et al., 2020). Additional characteristics of AP will be discussed throughout this review, but the key point is that an AP possessor identifies notes about as effortlessly and automatically as anyone with normal colour vision perceives the colour of an object. An *AP non-possessor* would not be able to achieve the same. A *relative pitch (RP) possessor* could only identify a pitch correctly if first given a reference tone of known pitch to compare with the test tone, and typically more slowly (Levitin, 1994; Levitin & Rogers, 2005; Takeuchi & Hulse, 1993). AP ability is mysterious in some respects, most notably because of its rarity (e.g., Deutsch et al., 2006; Miyazaki et al., 2012). Tonal language speakers are more likely to have AP (Deutsch et al., 2004, 2006, 2013). But even amongst expert musicians, AP is quite uncommon (Baharloo et al., 1998; Gregersen et al., 1999). The exact rate of AP in the general population is unclear. While a statistic of 1 in 10,000 is frequently cited, no empirical evidence supports this. One review suggests that the rate is at least 4% in experienced musicians (Carden & Cline, 2019), but this is of course still rather low. Deutsch (2013) summarizes well why this is so bizarre (p. 142):

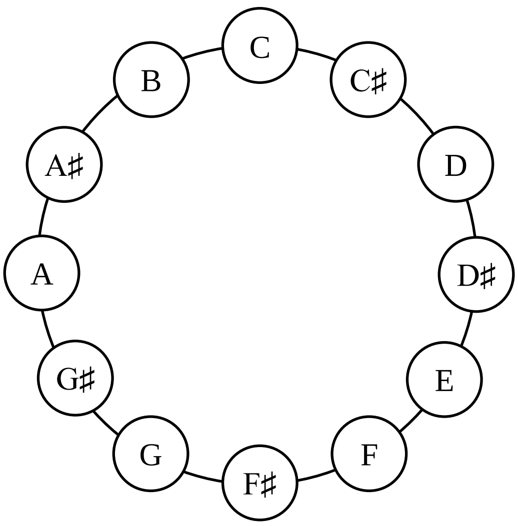
[1] Both fixed-do and letter notation (which are equivalent) will be used throughout this review. It is perhaps additionally worth noting that solfège syllables (do, ré, mi) are sometimes used in a non-absolute way in movable-do solfège, not to be discussed further in this review.

> "…note naming involves choosing between only 12 possibilities—the 12 notes within the octave… Such a task should be trivial for musicians, who typically spend thousands of hours reading musical scores, playing the notes they read, and hearing the notes they play."

Indeed, there are only 12 pitch classes in the chromatic scale, as illustrated in Figure 1. The notion that it is nearly impossible, even for experienced musicians, to acquire the ability to name notes by ear may seem ridiculous on its face. Imagine if I were to suggest that it would be impossible for you to learn the meaning of 12 words from a foreign language or the keypresses for 12 of the letters on a computer keyboard. Imagine that I further told you that only those born with a rare genetic advantage and/or those that began learning before a critical age of, say, 7 years old would have any reasonable hope of learning such a small set of pairings. As will be discussed shortly, however, such limits have been proposed for the case of AP ability, at least according to the standard narrative.

**Figure 1**

*The Pitch Class Circle*




The main objective of this review is to explore the learnability of AP. A first question that the review will discuss is why AP is difficult to learn in the first place. I will begin with the standard narrative on AP, but then follow this with a discussion of some alternative interpretations of this difficulty. I will next consider an important distinction between verbalizable (i.e., normal) AP and implicit AP. This will be followed by some past attempts at training adult AP non-possessors to acquire AP, with varying degrees of success. In addition to encouraging results with explicit learning tasks, some recent results with incidental learning tasks, though preliminary, are equally encouraging. The review concludes with a new perspective on the acquisition of AP along with some open questions for future research.

## Standard Narrative Regarding the Rarity of Absolute Pitch

As hinted at above, two key factors have been suggested as strong predictors of eventual AP ability: genetics and early music learning. A role for genetics was first suggested by Bachem (1955). Although there are a limited number of studies, sample sizes are often small, and methodology is often suboptimal (e.g., relying on self-reports of AP ability), there is reasonable evidence for the notion that genetics play a role in the development of AP ability. For example, AP possessors are much more likely to have first-degree relatives who are (also) AP possessors than are AP non-possessors (Baharloo et al., 1998, 2000; Profita et al., 1988). Similarly, concordance rates between identical twins are much higher than those between non-identical twins (Theusch & Gitschier, 2011). There is also a bimodal distribution of pitch naming ability (i.e., present or absent, with little variability between the two extremes; Athos et al., 2007; but see, Bermudez & Zatorre, 2009). Further research has discovered genetic correlates to AP ability (Theusch et al., 2009).

Other research has suggested a key role for early music learning (Baharloo et al., 1998; Chin, 2003; Deutsch et al., 2006; Miyazaki, 1988; Miyazaki & Ogawa, 2006; Sergeant, 1969). In particular, it has been proposed that there is a *critical period* for acquiring pitch naming ability. That is, if the individual does not start music training before some critical age, then eventual development of AP ability becomes nearly impossible. The critical period has been defined rather inconsistently from study to study, but is often considered to end somewhere around 7 years old (e.g., Miyazaki & Ogawa, 2006). In other domains, similar critical periods exist, for example for the learning of phonemic classes in the first year of life (Eimas, 1985) or the ability to obtain native level fluency in a foreign language (Kuhl, 2000; Newport, 1990; Russo et al., 2003; Vitouch, 2003). Research on AP ability has clearly indicated that the ability is much more common for early music learners (e.g., 40% of those who began music instruction before 4 years old in Baharloo et al., 1998), then becomes vanishingly rare for those that began music training later in life (e.g., <3% for those who began music training at 9 years old or older in the same study; see also, Deutsch et al., 2013). As will be discussed later, attempts at training AP ability are also more effective in children (e.g., Abraham, 1901; Bennedik, 1914; Crozier, 1997; Grebelnik, 1984; Miyazaki & Ogawa, 2006; Russo et al., 2003; but see, Cohen & Baird, 1990; for a discussion, see Petran, 1932). Further research by Gervain et al. (2013) suggests that the critical period for learning AP might be reopened pharmacologically with valproate. They observed better learning of 6 of the 12 pitch classes (presented in three octaves) in a group receiving the drug, though effects were small.

Although the genetic and critical period hypotheses could hypothetically be treated as opposing theories, others have suggested that these two factors interact to determine the presence or absence of AP ability (e.g., Wilson et al., 2012; for reviews, see Moulton, 2014; Zatorre, 2003), which has seemingly become the received view on the rarity of AP. Critically, the general assumption seems to be that an adult who does not already possess AP and that is not blessed with a certain biological predisposition to learn AP is unlikely to attain true AP (for reviews, see Chin, 2003; Deutsch, 2013). Though the present article will certainly not argue against a *role* of genetic predispositions or early learning, I will consider the idea that the above-mentioned general assumptions might be overstated. First, I will consider some other potential reasons why AP may be so rare.

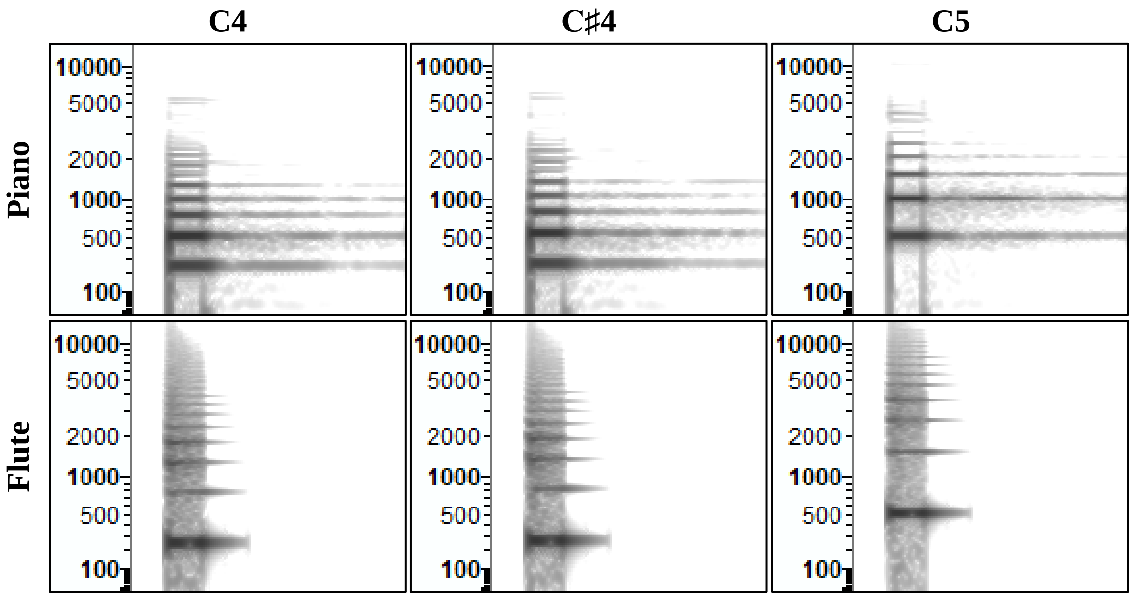
## Alternative Reasons for the Rarity of Absolute Pitch Ability

### The Complexity of Pitch Classes

One possible explanation for the rarity of AP ability is the inherent difficulty of what needs to be learned to master it. There are at least some ways in which the apparent simplicity of the associations to learn to develop AP might often be grossly oversimplified. As mentioned above, it is often pointed out that there are “only” 12 associations to learn between notes and note names. However, it is more accurate to say that there are 12 complex sets of associations to learn, that is, between 12 pitch *classes* and 12 note names. A *pitch class* is a set of all pitches that share the same “color” or “quality”, typically referred to as “chroma” as an analogy to the perception of colour. More concretely, a pitch class is the collection of all notes that we give the same note name (e.g., “mi/E”). Even assuming that the instruments are always exactly tuned correctly (and in the same musical temperament), all notes belonging to the same pitch class are far from identical, as notes can vary in both octave and timbre. This is illustrated in Figure 2 with synthetic short attack tones (audio files in electronic supplementary materials). The spectrograms in the first and third column all belong to the same pitch class (C/do), whereas the second column corresponds to another pitch class (C♯/do♯), which may not seem self-evident visually.

**Figure 2**

*Spectrograms of Single Notes Varying in Pitch (Columns) and Timbre (Rows)*




*Note.* Audio files (created with Ableton Live and spectrally analyzed with Audacity) are available in the electronic supplementary materials for each note.

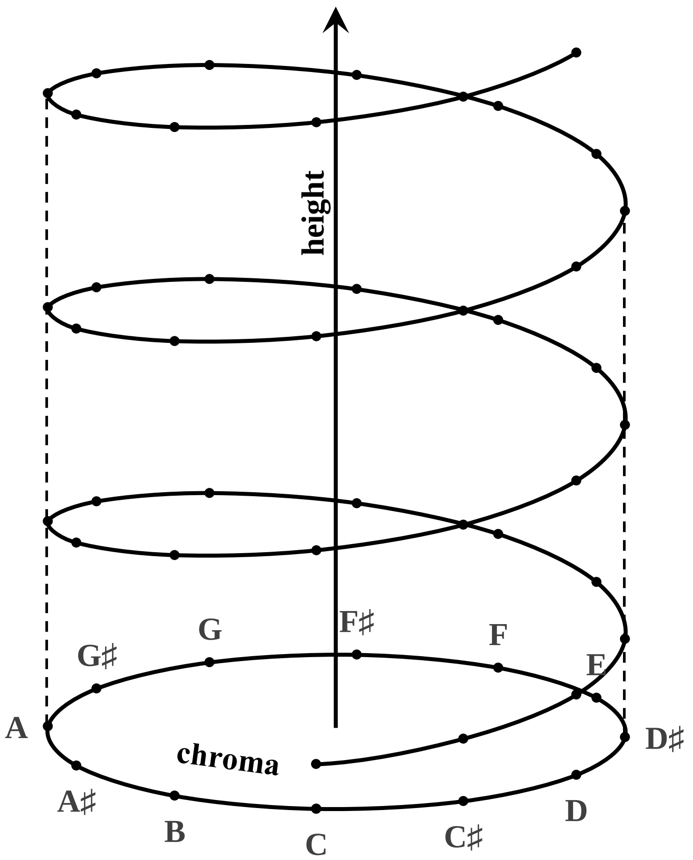
First, consider *octave*. Pitch perception is periodic. This means that as you increase the frequency of a root pitch (e.g., in semitone steps of $2^{1/2}$ in even-tempered occidental music), each successive note (C4, C♯4, D4, etc.) will be perceived as having a different colour until the frequency has been doubled. A tone is perceived as having the same colour (i.e., belonging to the same pitch class) of another tone with twice (or half[2]) the frequency of the first (e.g., 220 Hz for A3 and 440 Hz for A4). This is referred to as *octave equivalence* and is illustrated in Figure 3 in a modified helix representation of the pitch class circle (Deutsch et al., 2008; Shepard, 1964, 1982). The circular base of the figure represents the chroma or pitch classes and the vertical axis represents *pitch height*, the position of a note on a continuous scale from the lowest to the highest note. Adjacent semitones are similar in pitch height but belong to different pitch classes. Octave equivalence can be perceived as a second

[2] Or any other multiple of two.

dimension of an auditory stimulus (as will be discussed shortly) and is represented by the closeness of pitches in the same pitch class along the vertical dimension (e.g., dashed lines). Of course, there are very clear reasons why, say, C3 and C4 correspond to the same pitch class, but the fundamental frequencies are quite different. This might lead to some confusion, perhaps especially for musically naïve participants. For example, moving from a D3 to a C4 represents a significant increase in pitch but a “decrease” in pitch class.

**Figure 3**

*A Helix Representation of the Relation Between Pitch Height and Chroma*



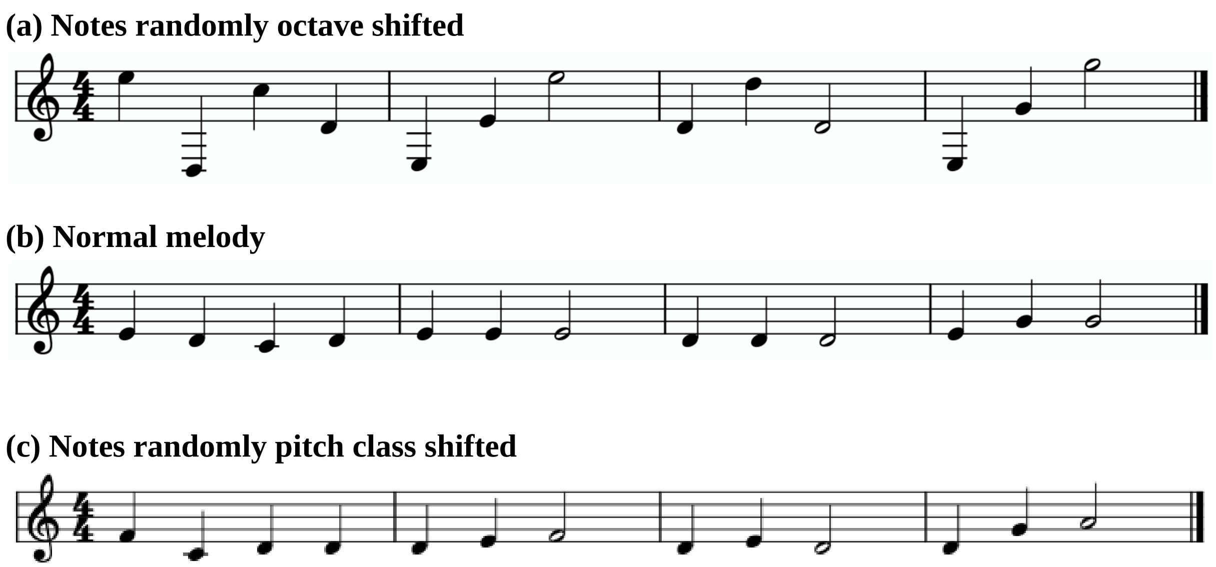

*Note.* Pitch height is continuous, increasing with each note. In contrast, pitch class (or chroma) is cyclical, with each pitch class repeating every 12 semitones (i.e., one revolution = 1 octave).

Indeed, the similarity between two pitches belonging to the same pitch class is not always salient for listeners. For instance, when asked to rate the similarity between two sequentially presented tones, non-musician participants do not rate two tones separated by 12 semitones (i.e., separated by an octave and both belonging to the same pitch class) as being more “similar” than two tones separated by, say, 11 or 13 semitones (Allen, 1967; Kallman, 1982). Rather, participants are more likely to determine similarity by closeness in pitch height (i.e., tones separated by 1 semitone are rated as very similar, tones separated by 2 semitones a bit less, etc.). Some experienced musicians do demonstrate octave equivalence in this situation, though there is much variability between individual musicians. Granted, participants were asked to determine the “similarity” between the two tones in these studies rather than to detect pitch classes explicitly, which may have been an ambiguous instruction (e.g., they may have rated “similarity” on the basis of pitch height intentionally even though they are able to hear octave equivalence). Still, the “equivalence” of two tones separated by an octave is clearly not obvious to all listeners.

Globally, notes of the same pitch class from different octaves are not easily interchangeable, even for musicians. For instance, a random sequence of notes within a single octave is much easier to notate than a sequence of notes that jump back and forth between two octaves (Deutsch & Boulanger, 1984). Similarly, detection of musical intervals is harder if there is a separation of one or more octaves between the two pitches (Thurlow & Erchul, 1977). As another example, a highly familiar song that is transformed to maintain the pitch classes but vary randomly the octave of each note becomes largely unrecognizable (Deutsch, 1972). Readers with an instrument might try playing the song in Figure 4a to experience this directly (audio files are also available in the electronic supplementary materials). However, there are certainly ways for even the most musically naïve to “hear” octave equivalence. For instance, after playing the non-transformed version of the same song, presented in Figure 4b, the transformed version in Figure 4a *does* become recognizable.[3] In contrast, randomly varying notes up or down by only one scale degree makes the melody unrecognizable even when you know the melody that you are trying to detect, as in Figure 4c.[4]

**Figure 4**

*Three Versions of the Same Melody*




*Note.* Audio files, created with MuseScore, are available in the electronic supplementary materials for each version.

Similarly, it is very easy to hear the "sameness" of two notes from the same pitch class (e.g., F4 and F5) played *simultaneously*, and this contrasts strongly with two notes of different pitch classes played together (e.g., E4 and F5). Yet other studies have observed octave equivalence in other ways. For example, if participants are asked to respond to certain groups of notes, but not others (i.e., a "go-nogo" task), in one octave, then there is a bias to respond to the same pitch classes of another octave in the same way in a non-reinforced

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[3] For those who may be unfamiliar (e.g., non-native English speakers), the melody is a popular song for children called "Mary Had a Little Lamb".

[4] As a minor detail, each individual note in Figures 4a and 4c has been (pseudo)randomly varied in exactly the same directions relative to the correct note the original melody (i.e., same, higher, or lower than the note in the original), except that in Figure 4a individual notes are transposed up or down an entire octave (e.g., the first note moves from E4 to E5), whereas the same notes are transposed in the same direction but only by one scale degree (e.g., E4 to F4) in Figure 4c.

transfer phase (Hoeschele et al., 2012). On the other hand, it seems that to obtain such effects, the use of pitch height (rather than pitch class) needs to be discouraged (Wagner et al., 2022; see also, Bongiovanni et al., 2023). Thus, perception of pitch height and pitch class are both possible, but pitch height is more salient. AP therefore does require more than just 12 simple associations. A learner must either learn to focus on the chroma (i.e., category learning) while ignoring pitch height or learn the pitch name for every note in every octave individually. The latter strategy is obviously less optimal. Within the 10 or so octaves of human hearing, this would represent more than 100 pitch-label associations to learn.

In addition to this (though perhaps more trivially), consider *timbre*. Timbre is the unique characteristics of the sound of individual instruments.[5] Musical instruments typically do not produce pure sine waves, instead producing resonating frequencies (Krimphoff et al., 1994). For example, a piano and flute can produce the same note with the same *fundamental frequency*, but the tone quality/colour will be different (see Figure 2). The two tones will sound similar, but not identical. These timbral variations are, however, probably less difficult for learners than octave equivalences (as discussed in further detail later), mostly because the fundamental frequency of a note is typically rather salient for most timbres (although some instruments produce undefined pitch, as is the case with non-pitched percussion instruments; see Eargle, 1995; Rossing, 2001; Rossing et al., 2004; Souza et al., 2015). Still, generalization across timbres requires learning to identify fundamental frequencies and not just the heard tone. In any case, the complications of multiple stimuli belonging to each pitch class makes it perhaps unreasonable to describe AP learning as something that should be easy.

[5] Note that I simplify slightly here by referring to differences between instruments, but there can also be differences in timbre within the same instrument (e.g., different bowing techniques on a violin, effects pedals on an electric guitar, or a limitless variability in timbre when using a MIDI instrument).

**The Lack of Appropriate Training**

Another possible (and starkly contrasting) explanation for the rarity of AP ability is that standard music instruction does not focus on extensive training of this ability. Auditory exercises are, of course, quite typical of conventional music training, but these exercises do not place a focus on learning to name pitches out of context. For instance, interval training involves listening to two notes (e.g., in isolation or in a known song) and learning to identify the change in pitch between the two (e.g., a perfect fifth, or 7 semitones, between the first and second "twinkle" in "Twinkle, Twinkle, Little Star"). This is quite clearly relative pitch training. *Relative pitch* is the ability to detect intervals between two notes.

Similarly, taking the above-cited example from Deutsch (2013), reading music notation, playing the notes on the instrument, then hearing the produced note does not involve direct AP training either. Specifically, the musician might know the name of the note represented in the notation, but they might not actively bring it to mind when learning to play a song. Relatedly, the produced note is heard, but the key focus in such training is between the musical symbols (i.e., not the names) and the procedural actions to execute. Furthermore, continued repetitions are more likely to rely on procedural repetition from memory rather than (re-)translation of the musical score. Abraham (1901) even goes so far as to state that (pp. 62; translated from original German):

> "In musical education everything is actually done to inhibit the development of an absolute awareness of tone, and next to nothing is done to instill it."

Note that this does not necessarily indicate a failure of the music classroom. Indeed, while learning to play an instrument or to understand music theory, relative pitches are often more pertinent than absolute pitches. Some even argue that AP is potentially detrimental in the music classroom (e.g., Moulton, 2014; Weisman et al., 2006; for a discussion, see Di Stefano & Spence, 2024), as it may interfere with RP processing. For example, Miyazaki

(2004) observed that AP possessors have more difficulty with transposition than AP non-possessors. Others view AP as an extraordinary gift and point to the disproportion number of world class musicians known to possess AP. Regardless, traditional instruction succeeds well in training a wide range of musical skills and knowledge. AP just happens not to be one of them.

For those who do wish to acquire AP, the question arises about how best to do so. Perhaps most optimally, AP training would involve repeated pairings of auditory stimuli and note names and nothing else (e.g., no musical notation, action execution on the instrument, or relative pitch comparison with known pitches). Indeed, as will be discussed later in this review, some recent research from our lab revealed *negative* impacts of musical notation on auditory pitch learning in a nonmusician sample (Iorio et al., 2024). Briefly, extraneous cues like this can cause *cue competition* (Kamin, 1969; Pavlov, 1927), whereby other associations are learned (e.g., between notes on the score and the corresponding fingerings on the instrument) *instead of* the associations between the auditory tones and note names. The above-mentioned AP-centric training is not typical of standard music training or practice. This fact alone may explain the rarity of AP. Indeed, unlike the analogy to colour naming (e.g., where children are repeatedly bombarded with colour names), association of heard pitches to the corresponding note names is not common in music listening or learning. If this latter explanation proves true, then AP learning in adulthood may be less hopeless than typically thought. Of course, the rarity of AP could be attributable to a complex interaction between all of the factors discussed thus far: the inherent difficulty of the associations to learn, the lack of extensive training of this particular skill, genetic advantages or disadvantages, and the benefits of early music training, a point to which this review will return later.

## Implicit Absolute Pitch in Memory

Although it is clear that the ability to *verbally* name pitches is rather rare, some research suggests that this is not due to any sort of inherent limit of the human auditory system to detect pitches absolutely. In fact, pitch discrimination is not necessarily superior in AP possessors (Bachem, 1954; Burns & Campbell, 1994; Levitin, 2004). Further, work on *implicit absolute pitch* seems to indicate that most people, even non-musicians, already possess a sort of unconscious AP ability. For instance, both AP non-possessing musicians (Gußmack et al., 2006; Sergeant, 1969; Terhardt & Seewann, 1983; Terhardt & Ward, 1982; Vitouch & Gaugusch, 2000; see also, Vitouch, 2003) and non-musicians (Schellenberg & Trehub, 2003; Trehub et al., 2008) are often able to detect when a song is played either in the correct key or is transposed. Similarly, Smith and Schmuckler (2008) found that musically untrained AP non-possessors were able to detect the difference between the true dial tone and pitch-shifted versions of the dial tone,[6] and Van Hedger et al. (2016) found similar results for the 1000 Hz sinewave tone commonly used to censor taboo words. Note that the above-mentioned results should not be possible with relative pitch processing alone. For example, recognizing that a song has been transposed is impossible in this manner, as all the intervals remain unchanged after transposition. Recognition of familiar music itself is also very rapid and automatic, achievable with as little as 500 ms of exposure (Filipic et al., 2010; Huijgen et al., 2015; Tillmann et al., 2014; see also, Bella et al., 2003; Jagiello et al., 2019; Schellenberg et al., 1999; Schulkind et al., 2003).

Participants are further able to generate notes relatively correctly when, for example, humming or singing a familiar song (Levitin, 1994). Participants do not always produce the exactly correct pitch, but are often quite close, and such results do not take into consideration

[6] For readers of younger generations, the dial tone was an extremely familiar tone that was heard every time a fixed telephone was not connected to a call, including when initially picking up the phone receiver.

the fact that knowing the correct pitches and being able to sing accurately are, of course, not the same thing. As a further example of implicit AP coding, when we do sing a familiar song on multiple occasions, there is relatively little variability in the key in which the song is sung (Bergeson & Trehub, 2002; Halpern, 1989). Collectively, work on implicit AP memory suggests that the average listener may not have particular difficulty in identifying (or even producing) pitches absolutely, but rather with the verbal *labelling* of such pitches (Hsieh & Saberi, 2008; Levitin, 1994; Schellenberg & Trehub, 2003; Vanzella & Schellenberg, 2010). Again, this may be related to the fact that we have significant practice in *hearing* specific pitches produced in specific contexts, but much more limited practice associating verbal labels to said pitches.

In the two-component model of Levitin (1994; see also, Levitin & Rogers, 2005), it is argued that absolute pitch memory is quite common, whereas pitch labelling (i.e., associating a name to a pitch) is much less so. It is argued that pitch labelling requires a pitch template mapping the linguistic labels (i.e., note names) to pitches. Only AP possessors are said to acquire this template. And after acquiring it, pitch labels are automatically retrieved by heard musical notes (Levitin & Rogers, 2005). In other words, detecting pitches absolutely in implicit absolute pitch memory is not problematic for late learners, but verbally labelling them is. On the other hand, though clearly the case that AP possessors have learned the verbal labels for the pitches and that AP non-possessors have not, it seems unusual to propose that the latter group cannot learn said labels. Why? Because the (complex) musical stimuli that AP non-possessors can identify absolutely in implicit AP studies *can* and already *are* verbally labelled by AP non-possessors with their song names (or “dial tone” in the case of Smith & Schmuckler, 2008).[7] It certainly does not seem to be the case that auditory pitch information

[7] Many of the studies mentioned above required recognition rather than song identification responses, but it is clearly the case that almost everyone (AP possessor or not) is capable of naming the songs that they hear.

is so fundamentally incompatible with verbal codes that associating tones to verbal labels is impossible.

In sum, there is good evidence for a sort of implicit AP in memory. Many or most participants can process pitches absolutely, but this absolute pitch perception is not linked to verbal labels. A further question is therefore whether participants are able to form the same sort of implicit (or even explicit) AP memory between pitches and the corresponding note names, as will be discussed in the following section.

## Learnability of Absolute Pitch

### Explicit Learning with Extended Training

Coherent with the notion that there is little hope of becoming an AP possessor for those who did not begin music instruction early are some early attempts at training adult AP non-possessors to strict levels of AP performance, which all failed. Often improvements are observed, but these improvements have varied from very small or non-significant (e.g., Gough, 1922; Heller & Auerbach, 1972; Meyer, 1899; Vianello & Evans, 1968; Wedell, 1934; for reviews, see Takeuchi & Hulse, 1993; Ward, 1999; cf., Mull, 1925), to encouraging but well short of true AP accuracy (e.g., Cuddy, 1968; Lundin & Allen, 1962; Terman, 1965; Van Hedger et al., 2015). Most of this work has involved explicit learning tasks in which participants must guess the identity of a pitch, which is followed by feedback of the correct note name. Other similar tasks involve initial discrimination training for learning one reference pitch before training the rest (Brady, 1970; Cuddy, 1968). Coherent with the critical period hypothesis, similar work has revealed that children between three and six years old are able to achieve AP-like performance with this type of training (e.g., Abraham, 1901; Bennedik, 1914; Crozier, 1997; Grebelnik, 1984; Miyazaki & Ogawa, 2006; Russo et al., 2003; but see, Cohen & Baird, 1990; for a discussion, see Petran, 1932). Indeed, results suggest that infants begin life treating pitches absolutely (Saffran & Griepentrog, 2001) and shift towards RP processing with development.

However, some relatively more recent work is more optimistic, suggesting that AP may be learnable by at least some adults. For instance, Van Hedger et al. (2019) trained AP non-possessors with high working memory capacity (a factor found to be important in Van Hedger et al., 2015) for eight weeks and tested them with a range of eight timbres and seven octaves. The training itself involved several different tasks, all with accuracy feedback. In the *simple speed* task, participants had to detect a named reference note (white keys only) in a series of trials. *Complex speed* was the same but with a faster pace, timbral variability, and wider range. *Accuracy training* involved force-choice guessing of individual notes of all 12 semitones. *Hypercomplex speed* replaced the first two in the second half of the experiment; the response window was shortened, the timbre range was expanded, and all 12 semitones were used as distracters. *Name that key,* also only in the second half of the experiment, was similar to accuracy training except participants had to detect the key signature of musical excerpts rather than individual notes. Most participants showed some improvements. Further, 2 of 6 participants achieved AP-level performance at the end of training, though both already had elevated levels of performance before training (i.e., just shy of "true AP" levels).

In Wong, Lui, et al. (2020), participants similarly learned via gamified trial-and-error learning to identify progressively more and more tones in more and more timbres and octaves. The training lasted for 12 hours in their Experiment 1, 15 hours in Experiment 2, and 40 hours (online) in Experiment 3. A small number of participants (6 of 43) across three experiments were able to learn all 12 semitones with at least 90% accuracy. A limitation of this study, similar to Van Hedger et al. (2019), is that the cut-off for inclusion in the study was rather liberal: greater than one semitone error in pre-test AP ability, which is exactly at the common cut-off to separate AP possessors and AP non-possessors. Thus, how much participants actually improved is unclear. Participants were also tonal language speakers, which might facilitate AP learning (Deutsch et al., 2004, 2006, 2009).

Wong, Ngan, et al. (2020) addressed the latter limit of Wong, Lui, et al. (2020) by studying non-tonal language speakers. Participants trained the 12 chromatic pitches of one octave and timbre for 20 hours. They started with only three pitches, and an extra pitch was added after completing a phase with at least 90% accuracy. Of the 13 participants, 2 were able to learn all 12 pitches within the 20 hours of training. For these two participants, performance improved particularly rapidly in the first 1h training period. Globally, accuracy increased and mean absolute deviations decreased in the sample. As a caveat, training and testing involved no timbral or octave variability, so it is less clear whether participants were learning pitch classes, fundamental frequencies, or even just associations to specific auditory stimuli (i.e., pitch + timbre cues), a point to which I will return later in this review.

## Incidental Learning of Absolute Pitch

The research discussed in the previous section is encouraging as it suggests that improvements in pitch identification are possible with extended practice, and some AP non-possessors may even be able to acquire AP. The extent to which learning could be accelerated (and potentially for more participants) with different learning procedures remains an open question. In that vein, some newer work has explored whether rapid improvements in pitch naming abilities are possible with an incidental learning procedure. Briefly, it is useful to highlight some of the key features of this type of learning approach that may make it particularly pertinent in the case of AP learning (e.g., in comparison to other approaches).

*Incidental learning* procedures involve non-intentional learning. In other words, participants are given a simple task (e.g., reading note names), but a hidden covariation is present in the task (e.g., non-target pitches that are predictive of target note names).

Participants are not instructed about the hidden regularity and are not given the goal to try to learn one, thereby making any learning incidental to the objective of the task. Learning of said regularities nevertheless occurs in a wide range of tasks, sometimes with, but often without, conscious awareness of what was learned.[8] Incidental learning effects are extremely robust and easy to observe in a wide range of domains. In the music domain, much of this research is analogous to artificial grammar learning or sequence learning tasks (for a review, see Rohrmeier & Rebuschat, 2012). For example, participants have been found to incidentally learn the hidden "grammar" rules used to create melodies (Saffran et al., 1999, 2000; Tillmann & Poulin-Charronnat, 2010). Similar research has found evidence for incidental learning of unfamiliar harmonies (Bly et al., 2009; Loui et al., 2009; Rohrmeier & Cross, 2009), sequences of timbres with identical pitches (Bigand et al., 1998; Hoch et al., 2013; Tillmann & McAdams, 2004), and timing information, specifically, temporal sequences (Brandon et al., 2012; Prince et al., 2018; Salidis, 2001; Schultz et al., 2013; Tillmann et al., 2011). An incidental learning task more analogous to the AP application to be discussed shortly has also been successfully applied to the initial familiarization with sightreading materials by non-musicians (Iorio et al., 2023; Schmidt et al., 2023).

One key advantage of incidental learning procedures is that they produce very rapid learning, appearing after only a few repetitions of each stimulus pairing (in some cases, after a single presentation; Lewicki, 1985, 1986; Lewicki et al., 1992). This has been observed in sequence learning (Nissen & Bullemer, 1987), the Hebb digits task (Mckelvie, 1987), hidden covariation detection (Lewicki et al., 1988), and the colour-word contingency learning task (Lin & MacLeod, 2018; Schmidt et al., 2010; Schmidt & De Houwer, 2016; for reviews, see MacLeod, 2019; Schmidt, 2021a, 2021b), among others. Adding the goal to try to learn the

[8] A related concept is *implicit learning*, in which learning is incidental *and* the acquired knowledge is not verbalizable (Berry & Dienes, 1993; Cleeremans et al., 1998; Perruchet, 2019; Perruchet & Pacteau, 1990; Reber, 1967, 1989; Shanks, 2005). Of course, true AP is verbalizable, so fully implicit learning is perhaps less pertinent for the case of AP learning.

pairings (i.e., during the same task used to study incidental learning) can slightly improve learning in some cases (Destrebecqz, 2004; Schmidt & De Houwer, 2012), though this comes at the cost of speed. In other cases, more explicit forms of learning can be detrimental, such as when regularities are too complex or difficult to consciously learn (Berry & Broadbent, 1988; Fletcher et al., 2005; Howard & Howard, 2001; Reber, 1976; Reber et al., 1980; Wulf et al., 1998). This is perhaps particularly pertinent to the case of learning AP, given the apparent difficultly of consciously learning said skill. Another advantage of incidental learning is that this form of learning produces more rapid and automatic effects on behaviour. For example, while both participants in an intentional and an incidental learning condition may learn artificial grammars, putting time pressure on participants often reveals advantages for incidental learning, both with musical (Bigand et al., 1998) and linguistic stimuli (Turner & Fischler, 1993). This is pertinent to the training of AP, as AP implies not only the ability to correctly identify pitches by ear, but also the ability to do so very rapidly and automatically (Bermudez & Zatorre, 2009; Miyazaki, 1988, 1990; van Hedger et al., 2019; Wong, Lui, et al., 2020).

In an initial set of studies applying incidental training to AP, Iorio et al. (2024) trained unselected non-musician participants with the seven notes of a C-Major scale in one octave. The goal was not to train true AP, strictly defined, but rather to determine whether (a) learning would be just as rapid as in all other incidental learning tasks, or (b) there is something fundamentally more difficult about auditory tone stimuli. On each trial, participants heard one of the seven pitches, and this was immediately followed by a note name presented in the middle of the screen. On the majority of the trials (90%), the note and note name matched (e.g., the note for “fa”/F followed by the note name “fa”), as illustrated in Table 1. Only rarely did the note and note name mismatch (e.g., the note for “sol”/G followed by the note name “do”, “ré”, “mi”, “fa”, “la”, or “si”). The task of participants was to ignore the auditory stimulus (note) and identify and categorize the note name with a keypress (i.e., each note name was assigned a different key). Learning of pitch names was observed in a few different ways. First, in an explicit pitch identification task (i.e., forced choice guessing of the names of the tones in a test of AP), accuracy significantly improved. Second, the impact of learned contingencies was rather automatic: participants were faster to identify note names preceded by the matching (congruent) pitch than by a mismatching (incongruent) pitch. In other words, even though the goal of the task is to ignore the auditory stimulus, participants learn the names of the heard pitches to a sufficient level of automaticity that they cannot help but be biased by the interpretation of the pitch.

**Table 1**

*Contingency Manipulation from Iorio et al.* (2024)

| Note Name | Auditory Stimulus | | | | | | |
|---|---|---|---|---|---|---|---|
| | do/C | ré/D | mi/E | fa/F | sol/G | la/A | si/B |
| do | 54 | 1 | 1 | 1 | 1 | 1 | 1 |
| ré | 1 | 54 | 1 | 1 | 1 | 1 | 1 |
| mi | 1 | 1 | 54 | 1 | 1 | 1 | 1 |
| fa | 1 | 1 | 1 | 54 | 1 | 1 | 1 |
| sol | 1 | 1 | 1 | 1 | 54 | 1 | 1 |
| la | 1 | 1 | 1 | 1 | 1 | 54 | 1 |
| si | 1 | 1 | 1 | 1 | 1 | 1 | 54 |

*Note.* Numbers indicate the relative trial frequencies of tone-name pairs. Congruent pairings are presented much more frequently than incongruent pairings.

The response time effects in the learning phase are also interesting for another reason. As previously mentioned, one key characteristic of AP is that it is very rapid and automatic (Bermudez & Zatorre, 2009; Miyazaki, 1988, 1990; van Hedger et al., 2019; Wong, Lui, et al., 2020). An analogy is often drawn to colour perception: an AP possessor hears the pitch class as directly as anyone with normal colour vision sees a colour (e.g., Deutsch, 2013). Being able to identify pitches with high accuracy but only if taking a long time to determine the pitch labels (e.g., with some kind of relative pitch comparison strategy) would typically not “count” as true AP. This automaticity has not only been measured in raw response times in an AP test phase, but also (analogous to Iorio et al., 2024) in auditory musical Stroop tasks (e.g., Akiva-Kabiri & Henik, 2012; Schulze et al., 2013; see also, Hamers & Lambert, 1972; Leboe & Mondor, 2007). For instance, Akiva-Kabiri & Henik (2012) asked AP possessors and non-possessors to read note names while ignoring an auditory tone. AP possessors were slower to read the note names when the tone was incongruent (e.g., the tone for do/C with the note name “sol”) rather than congruent (e.g., do/C with “do”). The same effect was not observed in AP non-possessors. Analogous to the colour-word Stroop effect (Stroop, 1935; for a review, see MacLeod, 1991), this result indicates that the notes are so strongly associated to note names in AP possessors that AP possessors cannot help but “translate” the auditory note stimulus into a note name, even though the task is to ignore the tones and read the note names. It is interesting that this same sort of automaticity is also observed in musically naïve participants after a brief training in Iorio et al. (2024) given how impossible it is supposed to be for adult non-possessors to acquire AP.

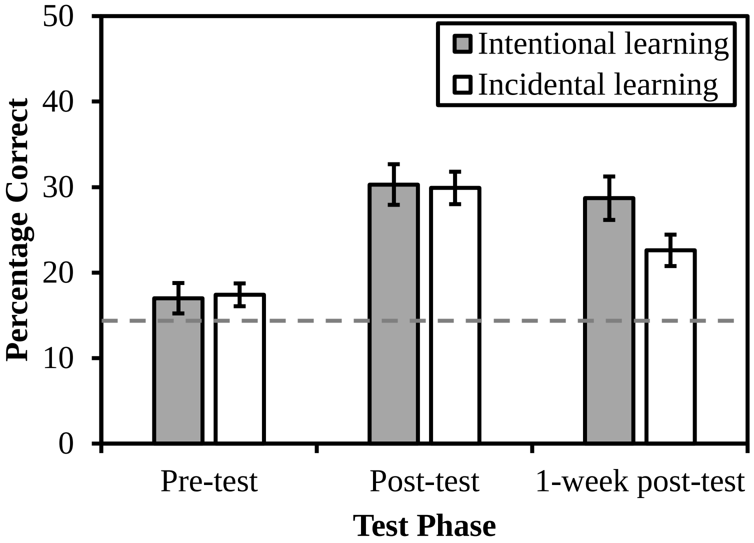
Incidentally, the same study of Iorio et al. (2024) also revealed that adding a second predictive cue, the note position on the musical staff, *interfered* with pitch learning. This is coherent with the previously mentioned notion that optimal AP training should focus only on the link between the auditory stimulus and note name. The negative effect of extraneous cues (e.g., note positions) can be explained by *overshadowing* (Pavlov, 1927). There are several different theories of overshadowing and related “cue competition” effects, such as blocking (Kaufman & Bolles, 1981; Mackintosh, 1975; Matzel et al., 1985; Miller & Witnauer, 2016; Pearce & Hall, 1980; Rescorla & Wagner, 1972; Sutherland & Mackintosh, 1971), but overshadowing is the observation that the learning of one predictive relationship (e.g., between note positions and note names) negatively impacts the learning of another predictive relationship (e.g., between pitches and note names) when the two predictive stimuli are presented together.[9]

AP non-possessor musicians also showed pre-post improvements in explicit pitch naming in another experiment of Iorio et al. (2024). This is interesting because these participants have already spent years learning music, hearing the notes whose note names that they know, yet have not acquired AP. This would seemingly suggest that these participants do not have a genetic advantage to acquire AP, yet comparable improvements were observed for these participants. In a third experiment, non-musicians showed significant retention in a surprise one-week follow-up test of AP (i.e., higher than pre-test and without substantial losses from immediate post-test). These data are presented in Figure 5 for a pure incidental learning group and for a second group given the secondary goal to try to deliberately learn the pitch-name associations. Such results clearly indicate that learning is not merely short-term. Alternative interpretations of these pitch learning effects in terms of a simple strategic use of the spatial compatibility between key order (left-to-right for ascending notes) and the pitch heights (i.e., low-to-high) were further ruled out with scrambled key orders in Experiment 2.

[9] A more classical example of overshadowing is an experiment where a rat is placed in a Skinner box and can avoid a foot shock (or receive a food reward) if it presses a lever at the appropriate time. Rats are perfectly able to learn that a lever press following a visual light cue or an auditory sound cue leads to reward (the typical control conditions), but often fail to learn about one of the two cues (e.g., the auditory cue) if *both* are always presented simultaneously (i.e., the light and the sound) during learning.

**Figure 5**

*Test Phase Results of Experiment 3 of Iorio et al.* (2024) *with Standard Error Bars*




*Note.* The dashed line indicates chance-level guessing.

In another series of ongoing studies, Henry et al. (2024) used a conceptually similar task, but with a few notable procedural changes. First, participants learned all 12 semitones of an octave, rather than just a subset of 7 (e.g., from the C Major scale, as in Iorio et al., 2024). Second, participants read the note names (i.e., rather than responding with a keypress). Third, notes were always congruent with the presented note name. During learning, automatic effects on behaviour were not measured.[10] However, post-test accuracy (and response times) in explicit pitch identification significantly improved relative to pre-test accuracy (and response times). This was true for fully correct accuracy (i.e., only exactly correct responses are counted as correct), accuracy allowing for semitone errors, and mean absolute deviation between the correct and guessed responses. Interestingly, accuracy was still increased after a one-week delay in a surprise retest, similar to Iorio et al. (2024) but with all 12 pitches of an octave.

[10] This was impossible as there were no incongruent trials to compare with congruent trials as a measure of learning.

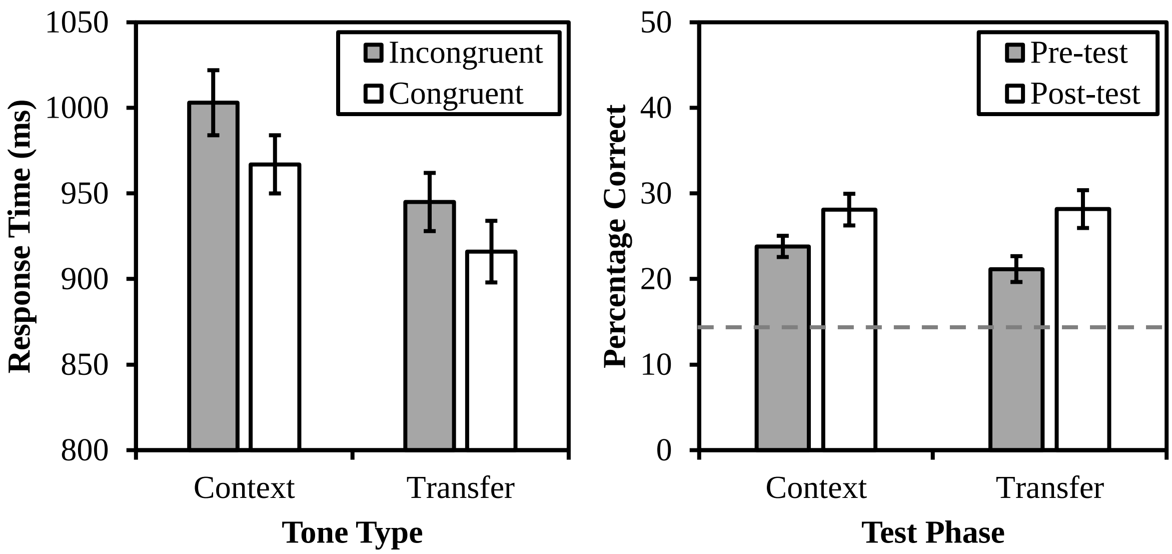
Crucially, improvements (and retention) were not only observed in the above-mentioned studies of Iorio et al. (2024) and Henry et al. (2024), but these improvement were observed after a very short learning phase of roughly 15 minutes. As previously mentioned, some encouraging results for the learnability of AP have been observed in extensive training studies (van Hedger et al., 2019; Wong, Lui, et al., 2020; Wong, Ngan, et al., 2020). Here, however, learning and automatization of pitch knowledge was extremely rapid, even when participants were musically naïve adults. Some participants even achieved AP level performance at the end of training (e.g., less the 1 semitone mean absolute error) despite chance-level pre-test scores. This was certainly not the case for all participants and other limitations of this work exist. For instance, extended training with these tasks would be useful to establish both (a) to what extent participants *continue* to improve with further training, and (b) what percentage of participants are able to eventually obtain high levels of performance.

Another question needing further exploration is the extent to which the above-mentioned studies demonstrate true learning of pitch classes. It could alternatively be argued that participants are merely learning associations between note names and highly specific sounds (e.g., the 7 or 12 auditory stimuli used in a given experiment), or *item-specific learning*. True AP ability is more general. Although many AP possessors may find identification of pitches easier with certain timbres or octaves (Lockhead & Byrd, 1981; Marvin & Brinkman, 2000; Miyazaki, 1989; Schlemmer et al., 2005) and there also exist narrower versions of AP that are specific to a familiar instrument (i.e., instrument-specific AP; see Reymore & Hansen, 2020), AP is *category-specific*. That is, an AP possessor can identify all tones belonging to each pitch class.

More work is still needed, but some recent work is encouraging. Henry and Schmidt (in press) used the same contingency learning procedure as Iorio and colleagues (2024) except that two timbres (e.g., piano and harpsicord) were trained as context stimuli. A third timbre (e.g., clarinet) was not trained: each pitch was presented equally often with all note names. Critically, the pitch identification learning trained with the context stimuli *transferred* to these latter transfer stimuli. Response times during the learning phase showed a learning effect (nearly indistinguishable from the context items), and explicit pitch identification after learning was increased also for the transfer stimuli, both as shown in Figure 6.[11] Responses in the post-test phase were not only more accurate, but response times were also faster than in the pre-test phase (not presented in Figure 6), also indicative of automaticity. These results clearly indicate category-specific learning and not merely item-specific learning. This is coherent with the idea that participants are learning pitch classes or at least something independent of timbre. Further work with a larger set of stimuli would be welcome, however.

**Figure 6**

*Learning Phase Response Times (Left) and Test Phase Percentage Correct Results (Right) of Henry and Schmidt* (in press) *with Standard Error Bars*




*Note.* The dashed line in the figure to the right indicates chance-level guessing.

[11] It might be noted from the figure that pre-test scores were above-chance guessing. Though the reason for this is unclear (e.g., perhaps indicating some undisclosed pre-existing knowledge of some participants or the use of a relative pitch strategy; for more on these possibilities, see Henry & Schmidt, in press), controlling for pre-test scores did not modify any of the results of the experiment.

In conceptually similar (ongoing) work (Henry & Schmidt, 2024), we tested for transfer of learning from two trained octaves (e.g., octaves 3 and 4) to an untrained octave (e.g., octave 5) in both non-musicians and musicians. In this work, we again observed increased post-test scores in explicit pitch identification (i.e., relative to pre-test) and automatic effects on response times during learning for both the trained and untrained octaves. However, effects, though statistically significant, were numerically small. Interestingly, this was also the case for the trained stimuli. The greater difficulty in transferring learning across octaves (i.e., relative to transfer across timbres) is consistent with single pitch learning studies of Bongiovanni et al. (2023), in which significant but attenuated transfer across timbres was observed for a single pitch, but transfer to another octave was very weak. Collectively, these results suggest that learning specific to pitch height is easier than learning specific to pitch class, but pitch class learning is nevertheless possible. Still, given that pitch height is more salient than pitch class, the most effective training of pitch detection abilities might involve a task that discourages the use of pitch height cues (coherent with the previously mentioned work of Wagner et al., 2022). Future research might therefore aim to increase attention to chroma while dissuading focus on pitch heights, for example, with some form of octave equivalence training (for which there seems to be little or no research that the author is aware of) or by training with Shepard tones (Shepard, 1964, 1982) that are ambiguous in pitch height but clearly defined in pitch class. Alternatively (and less optimistically), it could be that the difficulty of perceiving pitch class and ignoring pitch height may be the *reason* that AP is rare and this difficulty may be unsurmountable by most.

Other work with a more intentional learning task of Van Hedger et al. (2015) is also relevant. Rapid learning was also observed in a single session of 180 trials in two studies. Participants learned the 12 piano semitones of the chromatic scale in one octave in a more explicit guessing-with-feedback procedure. As in the studies discussed above, improvements were observed after training in an AP test phase. They also tested for generalization in a final test phase. This phase contained the original 12 piano tones, 12 piano tones from a higher octave (octave transfer), 12 guitar tones from the originally trained octave (timbral transfer), and 12 guitar tones from a lower octave (both octave and timbral transfer). Performance in this latter test was just below the conventional cut-off for statistical significance in Experiment 1, and just above in Experiment 2. This might suggest timbral and/or octave transfer, though the results were not clearcut and the four categories of tones were not tested separately. Further, the inclusion of the originally trained piano tones in the “generalization” test phase makes interpretation of these results unclear (i.e., because increased performance might be explained entirely by better performance for the trained tones).[12]

In summary, some recent research suggests that rapid improvements in pitch detection are possible with incidental learning procedures, and this acquired knowledge has automatic influences in behaviour (e.g., as indicated by response time effects during the learning phases). This learning is also not short-term, as effects are still observed after a retention interval. These results are coherent with the standard properties of implicit learning in other domains (Perruchet, 2008; Reber, 1992; Sun et al., 2007). Many questions remain unanswered, however. Whether participants are truly learning pitch classes (e.g., rather than just pitch heights) and how much improvement is possible with extended training is still not perfectly clear. At minimum, however, early results are encouraging.

## A New Perspective on Absolute Pitch

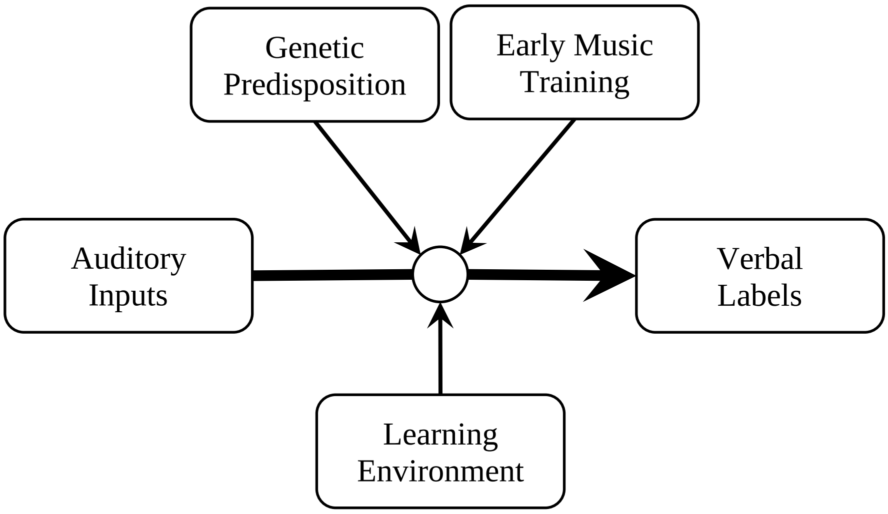
Taking together the discussions in the present review, we might consider a slight modification of the received view on the genesis of AP, as schematically represented in Figure 7. First, the difficulty of the associations to learn to master AP should not be

[12] See Henry and Schmidt (in press) for more on this.

understated. The wide diversity of stimuli belonging to each pitch class (e.g., with timbral variations and equivalence across octaves) makes for a difficult learning situation. The increased salience of pitch height cues over pitch class cues only adds to this difficulty. The learning of pitch classes therefore may be quite different than the common analogy to colour perception (see Di Stefano & Spence, 2024, for other critiques of this analogy). Learning associations between auditory musical inputs and verbal labels might therefore occur, but slowly. Exactly how rapidly learning occurs could be strongly influenced by the learning environment. That is, some tasks are probably better than others for promoting learning.

**Figure 7**

*Schematic Representation of the Modulatory Influences of Genetics, Early Music Training, and Learning Environment on Pitch Identification Learning*




Second, the extant data are sufficiently compelling to argue for a genetic contribution to AP. This should not be so surprising. Just as physical capacities (e.g., visual acuity) and psychological traits (e.g., working memory capacity, intelligence) vary from one person to another, variability in the natural capacity to learn AP surely exists. And, indeed, the long-term learning studies that have shown promising results with non-trivial sample sizes have only found a small number of participants showing particularly rapid learning (van Hedger et al., 2019; Wong, Lui, et al., 2020; Wong, Ngan, et al., 2020). Indeed, while the postulate of the current review is that AP might be learnable by much more individuals than usually imagined, there are surely many who cannot. The most obvious case of this is the deaf. Those with amusia are similarly probably incapable of learning AP. Amusia is the inability to consciously perceive and memorize pitches (for reviews, see Peretz, 2013; Peretz & Hyde, 2003; Tillmann et al., 2015). Amusics have difficulty, for instance, recognizing familiar songs and detecting pitch changes within a sequence of notes (Peretz et al., 2003). Generally, they have lower pitch discrimination thresholds and ability to detect intervals (Foxton et al., 2004; Jiang et al., 2013). It seems implausible that such participants could be trained to identify pitches absolutely, although there are some suggestions that *implicit* pitch perception might be preserved in amusics (e.g., Tillmann et al., 2007, 2014; for a review, see Tillmann et al., 2023). More globally, interindividual differences in pitch perception or memory could influence the learnability of AP.

Third, the learnability of AP might be particularly heightened early in development. As already discussed, similar critical periods exist for a range of other abilities (e.g., in early language learning). Heightened brain plasticity during early development (for a review, see Kolb & Gibb, 2011) certainly could make the learning of AP easier. Thus, it could be supposed that AP remains learnable at any age by some meaningful large percentage of the population, but that age of onset of musical training (similar to genetics) impacts the parameters of this learning, as discussed next.

In general, performance at a novel task tends to improve with practice in a lawlike manner in a wide range of tasks. This has often been referred to as the *power law of practice*, as performance improves in accordance with a power function (Grant & Logan, 1993; Logan, 1988, 1990; Newell & Rosenbloom, 1981; cf., Heathcote et al., 2000; Myung et al., 2000). Concretely, improvements are rapid early on in learning (e.g., faster response times or an increase in precision), followed by smaller and smaller improvements with increased training. One way to view this negatively accelerating function is that the more that one has already improved, the less room there is for further improvement. In the case of errors, the more the error rate has already decreased, the less it is possible to decrease errors further (e.g., it is impossible to have less than a 0% error rate). This can be represented with the formula: $a + bN^{-c}$, where $a$ is the asymptote to which performance improves with infinite practice (i.e., the lowest error a given participant could ever expect to have), $b$ is difference between initial errors and asymptotic responding (i.e., the amount of improvement theoretically possible for the participant), and $c$ is a learning rate determining how quickly the participant improves.

One key question is whether late music learning and/or the absence of a genetic predisposition impacts the asymptote of pitch identification ability or the learning rate. That is, are all or most people able to attain true AP, only at a much slower rate than someone who begins learning music at a younger age and/or has a better genetic predisposition (i.e., lower learning rate, but same asymptote)? Or is it the case that the maximum level of performance (e.g., with infinite practice) shrinks with age and/or a less advantageous genetic predisposition (i.e., lower asymptote, but same learning rate)? Figure 8 illustrates these two possibilities in simulated mean absolute deviation data (i.e., the mean difference between the guessed note and correct response in semitones).[13] At the start of training, pitch identification is at chance (pure guessing) and a score of zero would indicate errorless pitch naming. With variations in the asymptote of pitch identification but not learning rate (Figure 8a), some (perhaps most) participants will never achieve AP by a strict standard (e.g., less than 1 semitone error, indicated by the dashed line) even with infinite practice. If genetics and/or early music training affect the $a$ (asymptote) parameter, then this may be the true situation. In

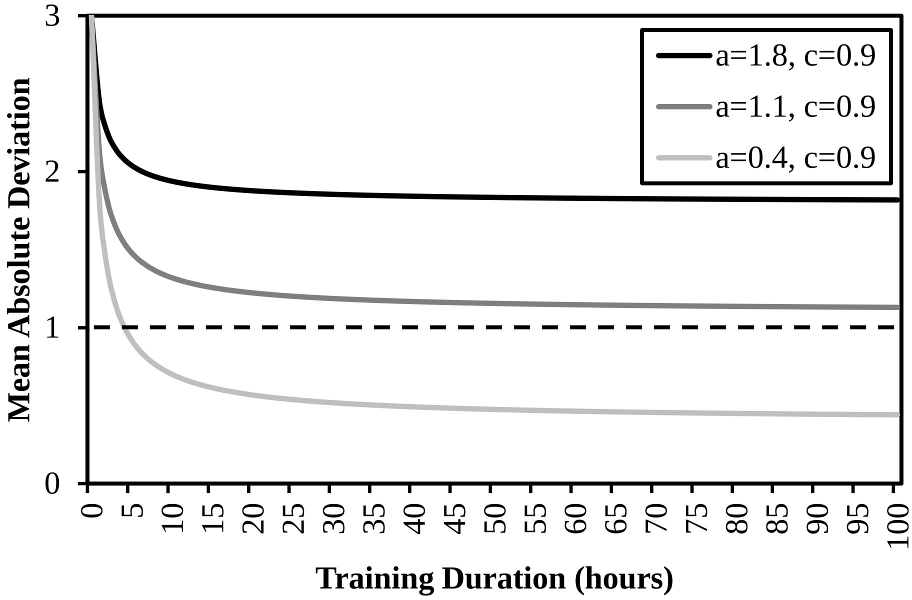
[13] Here, the simulated performance applies the same above-mentioned power function and assumes that everyone begins at chance guessing (3), such that $b = 3 - a$. The figure shows the results with variations in the other two parameters.

contrast, if the asymptote is the same (or universally low) for all participants, but the learning rate, *c*, varies, then everyone (or most) could achieve AP, only it may take some much longer than others (Figure 8b). The type of training (i.e., task environment) may similarly affect either the asymptote or learning rate. For instance, a task that better focuses the attention of participants on pitch classes rather than pitch heights might accelerate the rate of learning, *c*, only and not help the participant to achieve greater accuracy, *a*, with continued practice relative to training that focuses on pitch heights. Alternatively, training based on pitch height might fundamentally limit how much a participant can improve and switching to a learning strategy focused on pitch classes might help to overcome this limit (i.e., decrease the asymptote).

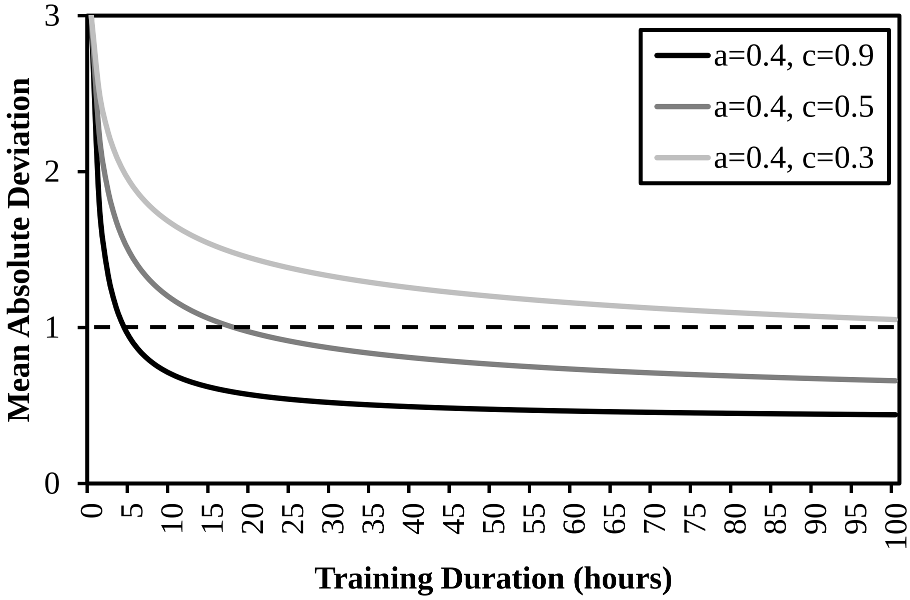
**Figure 8**

*How Modulations of Asymptote and Learning Rate Would Affect AP Learning Following the Power Law of Practice*

**(a) Same learning rate, different asymptote**




**(b) Same asymptote, different learning rate**




*Note.* The asymptote, *a*, is varied in the top figure, whereas the learning rate, *c*, is varied in the bottom figure. The improvement possible, *b*, is fixed at 3 – *a*. Scores below the dashed line would indicate AP-level performance.

More work regarding the task environment is desirable. Indeed, it is barely exaggerating to say that there are almost as many learning procedures as there are studies on long-term training of AP. For instance, one early distinction was between completely random trial-and-error learning versus a task in which a reference tone (e.g., C4) is initially learned, as previously discussed. The latter of these two strategies has been suggested as potentially superior. Of the limited number of studies that have *directly* compared these two approaches, however, results were mixed (Cuddy, 1968; Gough, 1922; cf., Heller & Auerbach, 1972) and sample sizes were not large enough to make the comparisons particularly meaningful. Whether learning an initial “anchor” pitch is actually desirable is therefore unclear. Indeed, an argument against such a strategy might be that it could shift focus to *relative* pitch processing rather than absolute pitch processing.

Similarly, the study of Van Hedger et al. (2019) included five different training tasks, as discussed above. Which of these is most effective was not tested, nor was the potential usefulness of combining several tasks into one training regimen. As another example, Wong, Ngan, et al. (2020) increased training of tones (and surrounding tones) that were the most misidentified in previous blocks to aid learners with tones that posed the greatest difficulties. However, there was no control group to test the usefulness of this procedural detail. Many of these modifications of the learning procedure in these studies do seem plausibly useful, but verification of this would be pertinent for determining optimal learning conditions.

The pertinence of systematically testing different learning procedures is highlighted by some (perhaps) unintuitive recent results from our lab. For example, Wong, Lui, et al. (2020) and Wong, Ngan, et al. (2020) started with a small number of tones to learn and then incremented this number as accuracy improved. Though this seems reasonable, a conceptually-related manipulation in our lab actually diminished learning (Henry et al., 2024). In particular, participants either learned all 12 semitones of an octave at once or in subblocks containing only 4 adjacent tones (e.g., do/C to ré♯/D♯ in one block, then mi/E to sol/G in the next, etc.). The idea was that the latter manipulation might reduce cognitive load and help participants to learn smaller sets of tones at a time. While both groups did improve, performance was notably worse in the latter group, contrary to initial hypotheses.

Relatedly, the use of supplementary music notation cues in Iorio et al. (2024) could have been hypothesized to aid pitch learning, but the reverse was true (as previously discussed). In short, more systematic between-group comparisons seem pertinent to determine optimum learning conditions. This is not always easy to do with time-consuming long-term learning studies, but shorter-term learning studies may be one way to assess such factors more feasibly. It will also be important to determine not only which tasks provoke the fastest learning, but also which tasks produce the most generalization to untrained stimuli (e.g., to untrained octaves or timbres). Such studies are particularly pertinent if we take seriously the possibility that AP might be learnable by most, but that it is also hard and time consuming for many (e.g., those without a genetic advantage and/or early music learning). The use of suboptimal training procedures does not, of course, assess this possibility fairly. Discovering the most optimal conditions for improving pitch detection abilities may therefore allow us to determine how learnable AP is and for what percentage of the population.

## Conclusion

In sum, learning AP is deceptively more difficult than it seems like it should be. The standard narrative is that acquisition of AP requires some interaction between a genetic predisposition for acquiring AP and early music learning during some critical period. While there is little doubt that both of these factors are important in AP skill acquisition, at least two other factors may explain the rarity of AP. First, the regularities to learn are perhaps inherently difficult given the wide octave and timbral variations within each pitch class. Second, even the most skilled musicians are unlikely to spend significant time with the right type of training procedure to actually learn to detect pitches absolutely. Another possibility is therefore that AP does remain learnable by adult AP non-possessors, but merely requires significant practice and in the right learning environment. Some recent results seem encouraging, but there is still a long way to go. Of course, the “holy grail” of research on the learnability of AP would be a training regime that can effectively train all or most AP non-possessor adults to obtain strict levels of AP performance. This has yet to be observed. The main hope of the present review, however, is to indicate some of the reasons why this might be the case and why hope may remain.

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