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Uncovering How Musicians Develop Perfect Pitch: A Literature Review

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Abstract
Introduction: Absolute pitch (AP), or more commonly known as "perfect pitch", is the rare ability to label pitches without needing a reference note. While its mechanisms are still unknown, there are many different theories regarding how and why some individuals develop AP, while others do not. Some argue that the ability is genetically inherited, while others argue that AP is a skill preferentially learned at a young age, with links to musical training and tonal language learning. This review investigates the possible factors that lead to AP development, as well as possible neurobiological underpinnings of the ability.
Methods: A literature search was conducted using scientific databases to reveal studies examining the impact of genetic, learning, musical training, language, and neuroimaging on AP development. Empirical studies written in English were examined for this review, with emphasis on how AP is differentially reflected in developmental and neuroimaging perspectives.
Results: Genetics, learning, musical training, and language all play a role in AP development, with some having a greater impact than others. Young children are easily taught absolute pitch using training programs, while it is much more difficult in adults. Furthermore, the apparent critical period for AP development closely resembles the time frame of the critical period of language acquisition. The phenomenon of AP is apparent through localized brain function, which differs from non-AP individuals.
Discussion: Genetic, musical training, and language all play an interconnected role in the development of AP. However, neuroimaging research is vastly separate, not integrating findings from other areas. Overall, looking at the various factors combined allows for a more complete understanding of AP.
Conclusion: Currently, there is a lack of research linking genetic and environmental influences on AP development with specific brain structure and function, which future neuroimaging research should seek to do. Understanding AP development benefits musicians and furthers an understanding of human perception of the auditory environment.

Keywords: absolute pitch; development; genetics; environment; neuroimaging

Introduction

Sound is integral to understanding the world around us. For someone with normal hearing, the drive back home after a long day of work might involve turning on the radio to listen to music, calling someone to clear up something about work, or pulling over to the side of the road after hearing an ambulance siren. Whatever it may be, without sound, none of this would be possible. We rely on sound daily for information about the world around us, whether it be warnings of danger or simply communication between one another.

Fundamentally, sound is a vibration that travels as propagating waves, with certain physical properties: frequency, wavelength, and amplitude. In the brain, the frequency of sound is perceived as the psychological phenomenon known as pitch (the sound we hear), one of the major components of auditory perception [1].

Among the general population, most people possess the ability to differentiate pitches. The ability to process pitch intervals does not seem to be learned or require any type of musical training; instead, evidence suggests that it is an ability with a wide genetic disposition. For example, one study showed that even newborn infants only two to three days old can tell when a pitch interval has changed compared to a control interval [2]. Being able to differentiate pitches is part of why we can distinguish between the voices of two friends or appreciate and enjoy listening to the melody and harmonies of a piece of music. Indeed, the inability to differentiate pitches in music, known as tone-deafness, is associated with problems in other areas, such as in the processing of speech intonation [3], recognizing of natural sentence breaks [4], and impairments in phonemic awareness (the separation of phonemes, which are units of sound that distinguish words; for example, *n* and *t* in the words *can* and *cat*) [5,6].

On the other side of the spectrum, some individuals are hypersensitive to pitch. Two phenomena have been identified to fall into this category: relative pitch and absolute pitch. Those with relative pitch can identify and name musical notes by first using another note as a reference point. Starting from the reference note, they can move note by note in a stepwise manner until they reach the unknown note to identify it. Other people can identify, name, and sometimes even reproduce any given pitch without needing to compare to a reference pitch, pulling the note out seemingly from thin air [7]. This ability is known as absolute pitch (AP), and unlike the ability to differentiate pitches found in the general population, is likely not innate. For American and European populations, studies have suggested that the prevalence of AP is less than 1 in 1000 [8]. Other than being able to identify pitches, which helps with tasks such as interval naming tasks [9], AP confers other musical benefits. For example, studies have shown that AP musicians are better at musical dictation (translating heard rhythms and melodies onto staff paper), scoring on average 95.4% on a musical dictation test – well beyond a score for non-AP musicians [10].

What makes it so some individuals develop AP, while most do not? Researchers have long been fascinated with the factors underlying the genesis of this rare ability, with many different theories and possible contributors suggested over the years. One viewpoint posits that AP is coded in genetic factors, and this predisposition for developing AP is passed down through genetic inheritance. Meanwhile, another viewpoint posits that AP develops as a result of individuals being taught to associate labels with specific pitches (i.e. associative learning), something that is learned with experience. One factor may be early musical training, which could enhance the association between pitch and label. A developmental perspective could help us understand the onset/critical period of AP and how early life experiences influence the development of AP. Specifically in early development, acquiring AP could also parallel language acquisition for tonal languages (such as Mandarin). Children learning tonal languages must attend to specific aspects of pitch contour/pitch information to understand different meanings of similar sounding words/phrases/syllables, which mirrors the functions necessary for absolute pitch. Furthermore, recent advances in the domain of neuroimaging have provided insight into the neurological underpinnings of AP, allowing researchers to compare the brains of those with AP to those without [11]. Although this emerging research has examined AP development, it is still unclear how exactly genetics, learning perspectives, and findings from neuroimaging (these various factors) contribute to the development of this ability.

The purpose of this literature review is to investigate and highlight findings regarding the various factors underlying the development of AP, specifically those related to development, language, and genetics, and how these factors may affect brain structure and function, as evidenced by neuroimaging. Currently, there is a gap in a cohesive framework underlying AP development, particularly linking neuroimaging findings with other types of studies. This review seeks to understand recent findings about AP development and relate them to specific brain functions, in hopes of developing a more complete understanding of AP.

Methods

Preliminary research was first conducted to identify areas of interest (such as musical training, genetics, language, genetics, and neuroimaging) regarding how individuals develop AP. A search was then conducted for relevant sources using academic databases such as PubMed, Scholars Portal Journals, and Google Scholar. The identified areas of interest were used as search terms, along with other keywords such as ‘absolute pitch’, ‘perfect pitch’, and ‘development’. Searches were restricted to empirical studies written in English, with the following additional guidelines: 1) The title and abstract relate to the research question, and 2) the main research question of the article examines how one of the identified areas of interest affects the development of AP.

A total of 150 sources were examined. Using the above criteria, 11 relevant sources were identified and used for this review. Additionally, 2 sources were obtained by subjecting the citations of accepted sources to the same criteria above. Specific manual searches were conducted when the initial search resulted in a lack of relevant sources for specific areas of interest. Results from these selected sources were critically analyzed to answer the research question. In total, 13 articles were chosen and analyzed for this review.

Results

Developmental Studies

Many studies have looked at developmental trajectories in individuals who possess absolute pitch. One common area of interest for studies is the age at which one begins their musical training. Research suggests that there exists a critical period for the development of absolute pitch. For example, Leite et al. tested 200 musicians from a Brazilian university for absolute pitch using a pitch identification task [12]. Participants were presented with randomized pitches and asked to name each note as fast as possible. Participants who correctly identified 85% or more of the pitches were considered to possess absolute pitch. Analysis of the characteristics of participants who met absolute pitch criteria found a higher prevalence of absolute pitch possessors who started their musical training early in life, with almost all starting musical training prior to 12 years of age. Other studies have similar findings; almost all those tested who possess absolute pitch started musical training prior to 12 years of age, where the earlier the training began, the higher the percentage of individuals with absolute pitch [13,14]

Learning

To test this developmental theory of absolute pitch acquisition, Sakakibara attempted to train 24 children (ages two to six) to develop absolute pitch using the Chord Identification Method (CIM), a method for absolute pitch [15]. The method involved several training sessions a day. In these sessions, a chord, represented by a colored flag, is played repeatedly to the child. A second chord, represented by a different color, is then presented after the first, and the two are played repeatedly until the child can identify each with 100% accuracy. Following, more chords are added, and this process repeats until the child can identify all 24 specified chords of the method with 100% accuracy. The first nine chords are specifically for white-key notes (as specified on a piano), and the remaining fifteen for black-keys. As each chord was added, children only moved on to the addition of the next chord if they achieved 100% accuracy on the current set of chords. On average, it took 18 months to complete the training program. Out of the 24 children who participated in the study, 22 completed the training program, all of which met thresholds to be classified as possessing AP, showing that young children can consistently be trained to develop it.

Van Hedger et al. also attempted to train absolute pitch with an older sample of participants ranging from 18 to 26 years old who all had some form of musical training and played their respective instruments for a significant period (more than eight years for all participants) [16]. The eight-week training program employed by the researchers consisted of two phases, which were each further broken down. For the first program of the first phase, participants were played a target note, which they had to identify as quickly as possible when the note was interspersed between non-targets. Later trials used sounds from different instruments as well as a larger octave range. A second program tested participants for accuracy, where they had to identify a note played in isolation. The second phase of training consisted of similar tasks but made more complex by the addition of more instruments and octaves for the first program, as well as having to name the key signature of a piece instead of an isolated note. Participants were tested for absolute pitch prior to and following completion of the training program, using a pitch identification task similar to those in previously mentioned studies. While all participants improved in performance on the pitch identification task, only one passed the absolute pitch threshold specified by the researchers. Compared to the children in the training program employed by Sakakibara, it is inferred that the adult participants had a much harder time developing absolute pitch. However, the children were trained for a much longer period of time and used a method that allowed for as much time as necessary to perfect the task. It is possible that under the same conditions, adult participants may find the same success in developing absolute pitch.

Language

The development of absolute pitch may be linked to the acquisition of language, specifically those with tonal inflections, such as in the Mandarin dialect. The idea is that the labeling of pitches required for absolute pitch mirrors the labeling of lexical tones for tonal languages. Thus, those whose first language is tonal in nature would be predisposed to learning how to label certain pitches. This connection was first suggested by Deutsch and colleagues, who found a greater prevalence for absolute pitch in Chinese music students compared to American music students, even when considering the age at which one began musical training [17].

A study by Lee and Lee looked at this relationship between pitch identification (absolute pitch) and lexical tone identification [18]. Using a sample of 72 musicians from Taiwan, they studied the prevalence of absolute pitch using a pitch identification task, as well as accuracy regarding identification of lexical tones, using a task similar to the pitch identification task, except with lexical tones. With no semitone errors allowed, 52 out of the 72 participants met the 85% threshold for absolute pitch; when adjusting for one semitone error allowed, an additional seven participants met the threshold. On the lexical tone identification task, participants were able to identify isolated tones with an accuracy greater than chance. However, the performance of absolute pitch possessors was no different than those without. Thus, speaking a tonal language may help form an association between pitches and their labels, but does not seem to improve one's ability to discriminate between them. These findings are supported by other similar studies on tonal language populations [19,20].

Genetics

The possibility that absolute pitch can be inherited is another area of interest regarding the development of absolute pitch. Theusch et al. genotyped 73 families of differing origin with at least one non-parent-child pair with absolute pitch, looking for significant linkages in the genome [21]. One major linkage on chromosome 8 was discovered for families of European descent. This region has several nearby protein-coding genes, one of which, ADCY8, is expressed exclusively in the brain, and is thought to play a role in learning and memory. How exactly these genes may contribute to absolute pitch development is unknown, as is whether absolute pitch is a predisposed ability passed down generations.

Neuroimaging

Several neuroimaging studies have compared brain structure and neural functioning of those with and without absolute pitch. These kinds of studies provide insight into the neural correlates of absolute pitch. A study by Loui et al. used functional magnetic resonance imaging (fMRI) on 15 absolute pitch possessors and 15 non-possessors during a music listening task, where participants judged emotional arousal [22]. This task was chosen (as opposed to a pitch identification task) to prevent bias in neural activation of those with absolute pitch. To this effect, both groups rated emotional arousal similarly, with no significant differences.

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The fMRI scans taken prior to and during music listening for each group were then compared to look at differences in brain activation. Both groups were found to have significant activation in the bilateral Heschl's gyrus (HG), superior temporal gyrus (STG), and the middle temporal gyrus (MTG). The degree of neural activation in those with absolute pitch was higher than in those without; the greatest difference in activation was found in the left STG, suggesting left-hemisphere dominance for absolute pitch possessors. This is consistent with previous research that suggests that the STG plays an important role in distinguishing pitches [23]. Meanwhile, the MTG helps with the processing of language and semantic information, as well as multimodal sensory integration [24,25]. Loui et al. also used graph theory analysis to study the degree of functional connectivity, finding an increased degree and strength of connectivity in the superior temporal region of absolute pitch possessors compared to non-possessors [22].

Brancucci et al. also found left hemisphere dominance in absolute pitch possessors, in the form of a right ear listening advantage [26]. Twenty-two AP musicians and 22 non-AP musicians performed a dichotic pitch identification task. A tone is presented in one ear, while the other ear was presented with white noise. Compared to non-AP musicians, AP musicians had faster reaction time and were overall more accurate for tones played in the right ear. Since central auditory processing of sound input is contralateral (i.e. sounds from the right are processed by brain regions in the left hemisphere), Brancucci et al. supports the heightened left hemisphere activation Loui et al. found with fMRI. These findings are also consistent with neuroimaging research using other methods, such as Matsuda et al. Using electroencephalography (EEG), they also found a left hemisphere dominance in pitch perception for AP musicians compared to non-AP musicians [27]. Altogether, the research suggests that left hemisphere processing is important in tone perception for those with absolute pitch; their ability may be explained by heightened activation in areas of the left hemisphere important for pitch recognition and identification.

Discussion

The results looked at possible factors that could explain why some individuals develop AP while others do not, including genetic inheritance, musical training, language, as well as neuroimaging of brain structure and neural functions of those with and without AP. There is evidence that all aforementioned areas of interest contribute in some way to the development of AP, though some more than others.

The present research most strongly supports that the major contributor of AP development is learning the association between pitch and its label. The training program employed by Sakakibara provides direct evidence that children can be explicitly taught to have absolute pitch, as children without AP were taught to associate pitches with corresponding labels and resulted in a 100% success rate in developing AP in its participants (not accounting for the children who did not complete the program) [15]. The children in the study had varying previous experience with music (with some children having no prior exposure to musical instruments), showing that an abundance of musical experience is not necessary for AP development.

Furthermore, research also supports the idea of a critical period in childhood for AP development, with a low chance of AP developing later in adolescence or adulthood. Attempts to train AP in adults, such as that by Van Hedger et al., were not as effective as those on children, even when both groups were trained with similar methods [16]. Compared to the 100% success rate with children in the study by Sakakibara, the attempt with adults resulted in a much lower success rate. The adult participants that were closest to or at the AP threshold following completion of the eight-week training program were also the ones who scored the highest on a preliminary test of pitch discrimination prior to the training, suggesting that they were already better at associating pitch and label compared to other participants. Additionally, all participants had some form of prior musical training starting at a young age. Thus, it is possible that they learned the pitch-label association to an extent as a child, with the training program helping to strengthen these associations over a short period of time. However, given the low sample size of this study, the results may be reflective of only the abilities of the individual participants and may limit generalizability. Furthermore, the differing length and method of the two studies may partially explain the difference in success rate. Future studies should employ training programs of similar length with adults and with larger sample sizes.

Studies regarding the age of onset of musical training for AP development also support a critical period for learning AP. There appears to be an inverse relationship between age of onset and the proportion of the sample of participants with AP, as the highest proportion of AP possessors (compared to non-AP) was found in those who began musical training the earliest. Specifically, those under seven years old were found to be most likely to possess AP, which decreased as age increased up to around twelve years [12]. A very low percentage of participants who began musical training after 12 were found to have AP across many different studies, suggesting that this age marks the end of the critical period for AP development. The possible critical period for AP development also closely mirrors that for language acquisition, which states that language develops most readily when the individuals is between ages five and twelve (around when puberty begins), after which language acquisition is less successful and more difficult [28]. Indeed, research suggests that one must begin learning a language prior to 10-12 years old in order to reach native-level proficiency [29]. This is hardly surprising given the similarity between learning a tonal language and learning AP, as supported by several studies mentioned above [17-20].

Out of all the reviewed domains, there was the least amount of research on genetic factors involved in AP development. This could be because of a variety of reasons: the use of a limited number of databases may have reduced the number of studies that could have been included, or it may be because of the behavioral complexity of the trait, as AP development involves many different neuropsychological functions, including auditory perception, associative memory, working memory, and inhibition. Nonetheless, the research reviewed supports the idea that genetics do contribute to AP development, finding several linkages that differ depending on ancestry [32]. Of interest is the gene ADYC8, which is thought to encode a protein that may play a role in the learning and memory processes necessary for AP. However, current knowledge on how the ADCY8 gene and the protein it encodes affects these processes is limited.

While studies regarding language, musical training, and genetic factors of AP often look at these together, neuroimaging studies in this field rarely integrate these factors. Within these studies, they widely agree upon a left-dominant hemisphere in AP possessors, as well as heightened activation in certain auditory brain areas, such as the STG, HG, and MTG. Future research should seek to relate neuroimaging findings with others. For example, one could study brain structure and function in children prior to and after an AP training program. This type of research would help clear up whether those who develop AP already have abnormally high function in these auditory brain areas, or if learning pitch-label associations are associated with localized brain activation. Other areas of interest include whether tonal language and musical pitch are processed in the brain in a similar manner (if language processing centers such as Broca's area and Wernicke's area mirror development in the aforementioned areas related to AP), and whether the protein encoded by ADCY8 (among others) is overexpressed in individuals with AP, which would support a high genetic predisposition for this ability. This type of research would further the understanding of how environmental and genetic factors contribute to altering brain structure and function of those with AP.

Conclusions

The development of AP depends on the interactions between many different factors, mainly between genetic factors and learning from the environment in childhood (involving language associations and musical training). Furthermore, AP is reflected in the form of different brain functions for those with and without it. Altogether, this makes AP an interesting chance to study the interactions between genes and environment, and how that is reflected in differences in brain structure and function. More neuroimaging research could provide greater sensitivity in investigating the relationship between these genetic and environmental factors, and the neural correlates of AP. AP is not only an interesting phenomenon but leads to real world advantages for musicians; learning about AP and its development could potentially make AP much more prevalent in the future, benefitting future musicians and providing a more nuanced view on how humans perceive their auditory environment.

List of Abbreviations Used

AP: absolute pitch
CIM: chord identification method
fMRI: functional magnetic resonance imaging
HG: Heschl's gyrus
STG: superior temporal gyrus
MTG: middle temporal gyrus
EEG: electroencephalogram

Conflicts of Interest

The author(s) declare that they have no conflict of interests.

Ethics Approval and/or Participant Consent

This review did not require ethics approval and/or participant consent because this is a literature review.

Authors' Contributions

SY: designed the review, collected and interpreted data, drafted and revised the manuscript, and gave final approval of the version to be published.

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