Unique brain structure and function in people with absolute pitch

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Abstract

Affecting roughly 4% of Brazilian music students (Carden & Cline, 2019), absolute pitch (AP) is the ability to identify and produce pitches without reference (Baharloo et al., 2000). It is a rare phenomenon that has intrigued researchers and musicians alike. This literature review examines the process of pitch perception for people with AP, especially as it compares to people without AP, as well as their unique brain structure and function, focusing on specific regions of the supratemporal plane. Finally, the review will cover potential limitations, areas of further study, and musical applications of this research for understanding auditory processing, genetics/epigenetics, and musical aptitude.

Introduction

Pitch is a sound wave's frequency, defined by how many times a wavelength repeats itself in a given period (Figure 1). Most pitched sounds, however, contain multiple frequencies. The lowest frequency is called the fundamental frequency, which defines the pitch of the sound. Harmonics (or overtones) are positive integer multiples of the fundamental frequency and give the sound its quality, or timbre (e.g., what distinguishes the sound of a voice from a piano) (Figure 2). The set of all harmonics is called the harmonic series (or overtone series) (Figure 3). The presence of the harmonic series in a sound is what makes it a simple tone (no harmonics) or a complex tone (has harmonics) (Oxenham, 2012).

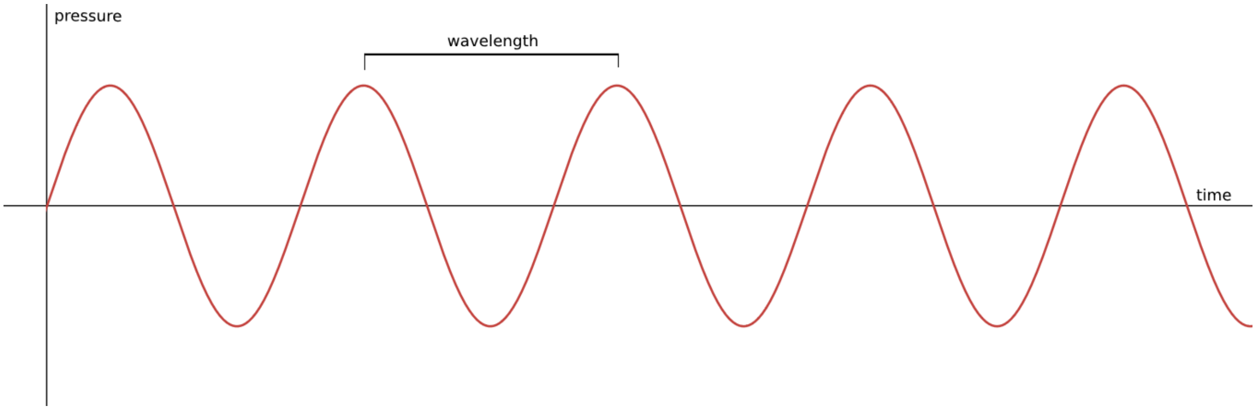

Figure 1. An arbitrary time-pressure graph depicting the waveform of a sine wave. The amount of times the wavelength repeats itself in a given period of time is called the "frequency" of the sound. Frequency is what defines pitch.

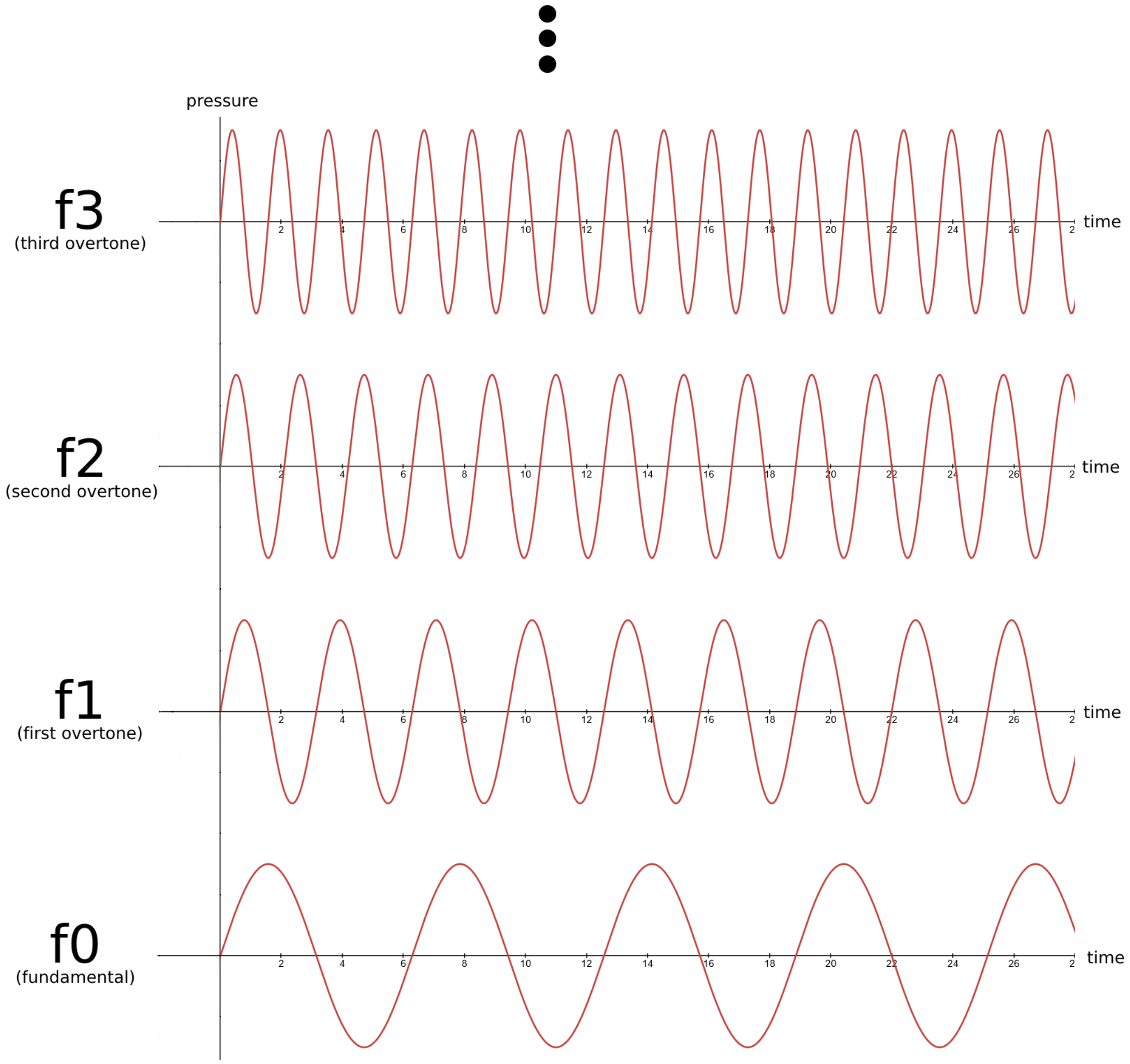

Figure 2. A series of arbitrary waveforms depicting a pitch and its overtones/harmonics. The harmonic series continues infinitely. The frequency of the overtones are positive integer multiples of the fundamental. All the frequencies are sounded at the same time.

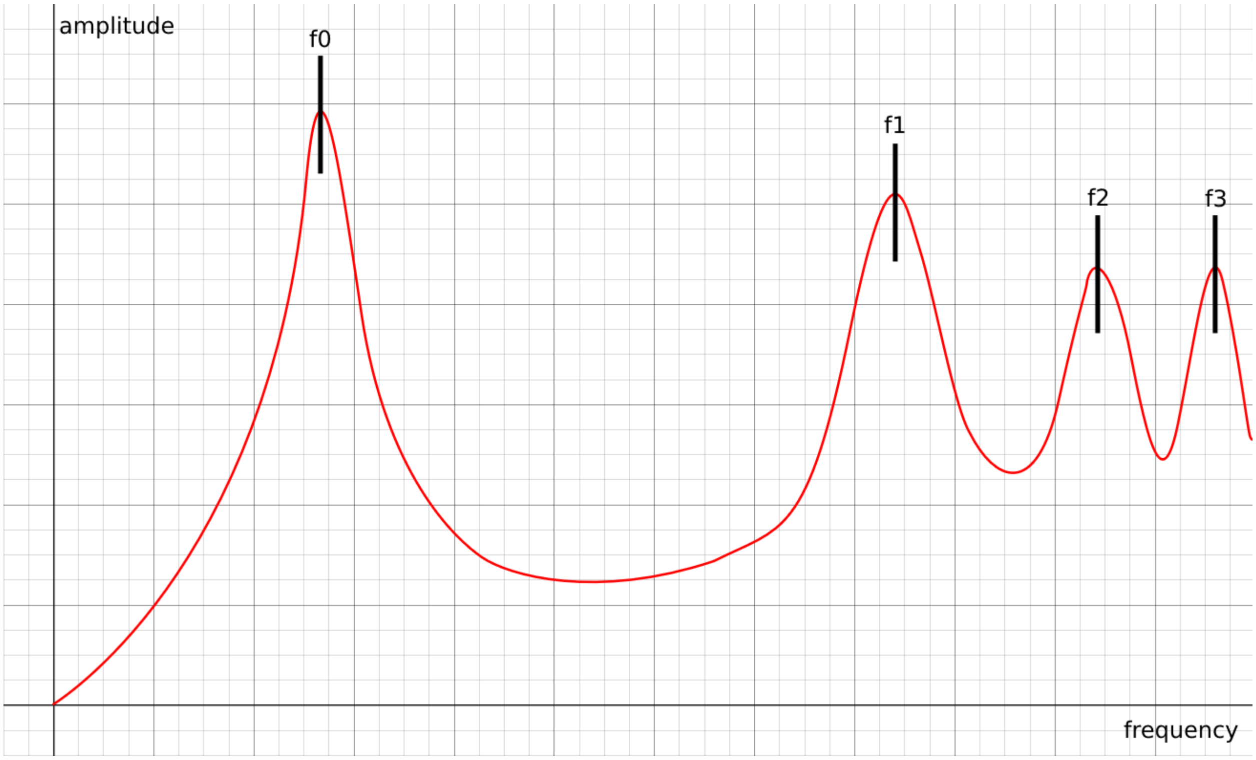

Figure 3. An arbitrary frequency-amplitude graph depicting a pitch and its harmonics. The volume, or amplitude, of different harmonics influences the quality of a sound, also called “timbre.” Timbre is what distinguishes the sound of a voice from a piano, even if the pitches played are the same.

Pitch perception for people without AP starts in the outer ear, where sound enters the ear canal and makes its way to the eardrum, which sends vibrations through the cochlea. Different sets of frequencies activate different parts of the cochlea. These parts are called cochlear filters and send signals to the temporal lobe that indicate which specific frequencies are being heard. The temporal lobe then processes the pitch of the tone (Oxenham, 2012). The pitch would be stored temporarily and remain unnamed in working memory. If the pitch is heard simultaneously or in sequence with other pitches, all the pitches would be stored in working memory and the relationship between their frequencies is used to communicate quality or emotion. If the pitch is heard by itself, the brain would only have general tone height (how high or low a pitch is) to make judgments based on, along with timbre and volume (Levitin & Rogers, 2005).

Aside from pitch, other auditory information that is processed includes timbre, amplitude (volume), and spatial information (where the sound is coming from) (Oxenham, 2012). Spatial information is processed through the dorsal auditory pathway (DAP), involving the Heschl’s gyrus (HG), planum temporale (PT), supramarginal gyrus (SMG), and dorsolateral prefrontal cortex (DLPFC). Non-spatial information is processed through the ventral pathway, involving the Heschl’s gyrus (HG), planum polare (PP), temporal pole (TP), and ventrolateral prefrontal cortex

(VLPFC) (Figure 4) (Rauschecker & Tian, 2000; Rauschecker, 2015). Pitch information is used to discriminate between and track auditory objects, aiding in processing spatial information (Griffiths & Warren, 2002; Warren et al., 2003b).

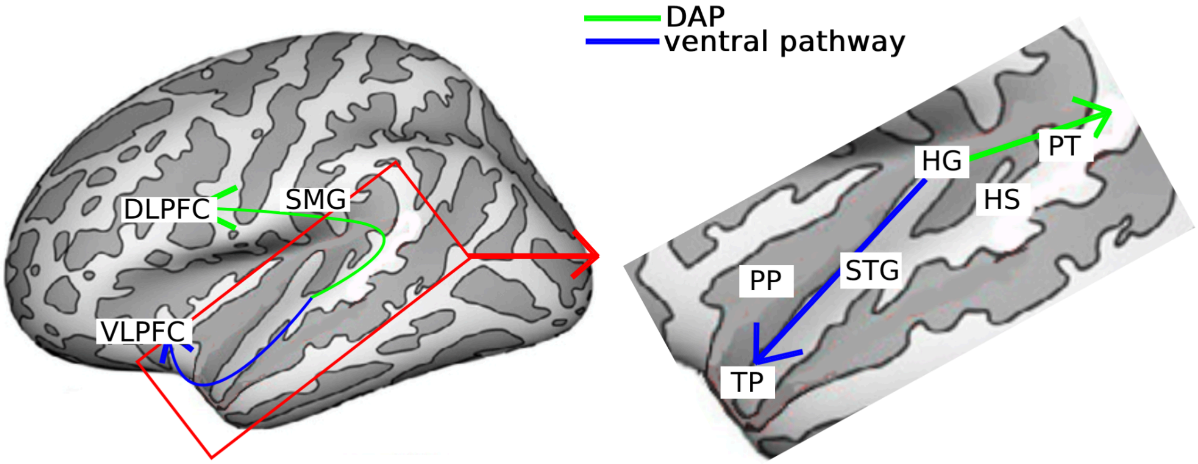

Figure 4. The brain and the supratemporal plane. The dorsal auditory pathway (DAP) processes spatial auditory information (where a sound is coming from). The ventral pathway processes non-spatial auditory information. Important regions of the temporal cortex notated are the Heschl's gyrus (HG), planum temporale (PT), supramarginal gyrus (SMG), dorsolateral prefrontal cortex (DLPFC), planum polare (PP), temporal pole (TP), and ventrolateral prefrontal cortex (VLPFC).

Musicians often concern themselves with pitch to construct melodies (sequential pitches) and harmonies (simultaneous pitches). To name pitches and make communicating pitch information easier, Western music takes advantage of octave equivalency, the idea that two pitches are the same note if their frequencies are multiples of each other by a power of 2. It divides the octave into 12 notes, named after letters of the alphabet (Burns, 1999).

The ability to identify the name or produce the frequency of a specific note without reference is called absolute pitch (AP), known among musicians as "perfect pitch" and thought to be a result of rigorous early musical training and genetics. Musicians with AP, known as AP possessors, only make up roughly 4% of Brazilian music students (Carden & Cline, 2019). Musicians without AP, known as nonpossessors, often rely on relative pitch (RP) to deduce the names of notes. Similar to how a painter would use a reference image to recreate a setting or subject, RP uses a reference pitch (of which the name is given), and judges the distance between the two notes to estimate the name of the unknown pitch.

AP has been a source of curiosity and envy for researchers and musicians alike, so understanding this phenomenon could reveal information useful for both academic and musical purposes. In this review, we will compare and contrast the differences in brain anatomy and activity between AP possessors and nonpossessors.

The process of pitch perception in AP possessors

The process of pitch perception in AP possessors involves two main subprocesses: perceptual and associative (Ward & Burns 1982; Levitin & Rogers, 2005). The perceptual subprocess involves sensing auditory stimuli and extracting pitch chroma, which is the quality that distinguishes different pitches in an octave. Which exact characteristic of sound is used to identify pitch chroma is unknown, although pure frequency (e.g., the brain calculates the pitch as exactly 440Hz, and names it “A”) is unlikely, since AP categories can be shifted significantly even after full development (Hedger et al., 2013). The associative subprocess involves comparing the pitch chroma to an existing pitch template (a collection of names that correspond with specific pitch chromas), and describing the pitch with a verbal/conceptual label.

The perceptual subprocess begins with auditory information entering the ear, as detailed in the introduction. After being pushed through the cochlea, auditory information is extracted and processed in different regions of the brain. Which exact region of the brain is responsible for pitch chroma extraction is unknown, but the greater anterior superior temporal plane area is most likely (Warren et al., 2003b). AP possessors are found to activate the posterior Heschl’s sulcus and anterior planum temporale (Barker et al., 2012; Kim & Knosche, 2017), as well as the superior temporal gyrus and planum temporale earlier and more extensively than nonpossessors (Figure 4) (Gaab et al., 2003; Levitin & Rogers, 2005). These regions work together to extract pitch chroma, and the early activation of some of them is essential to the involuntary nature of AP pitch perception.

After pitch chroma has been extracted, the AP possessor compares it to a pitch template, which is stored in long-term memory. It would be easy to think that medial-temporal structures, such as the hippocampus, would be involved in the associative subprocess, since they serve many listening and memory-related purposes, but they are not important to AP pitch perception. This is proved by rare cases of AP possessors undergoing epileptic surgeries. After an amygdalohippocampectomy of the right hippocampus and amygdala (Suriadi et al., 2015) or an anterior temporal lobectomy of the left hemisphere (Zatorre, 1989), patients retained their AP.

Instead of the hippocampus, the posterior dorsolateral frontal cortex is the main region involved with the associative subprocess, This region is found to be involved with the conditional association in memory (Petrides, 1995; Zatorre et al., 1998), which means that it stores information associating two otherwise unrelated stimuli or ideas, in this case, a pitch chroma and the conceptual name it corresponds to. This is further supported by studies that find that the posterior dorsolateral frontal cortex helps musicians (AP possessors and nonpossessors alike) label intervals (specific distances between two notes), as well as nonmusicans label chords (three or more pitches sounded simultaneously) (Bermudez & Zatorre, 2005), demonstrating the dorsolateral frontal cortex’s role in naming stimuli. After being processed in the posterior dorsolateral frontal cortex, the pitch chroma is fitted into a nominal category and the AP pitch identification process is completed involuntarily (Levitin, 1994).

It should be noted that there have been signs that AP pitch perception may involve visual and comprehensive components to pitch naming. The occipital and parietal regions of the brain have shown significant activation in AP possessors during pitch identification tasks (Wu et al., 2008), although research on this topic is limited.

Exaggerated lateral asymmetry in AP possessors

It’s widely known that the lateral asymmetry of the temporal lobe of AP possessors is exaggerated towards the left hemisphere (Schlaug et al., 1995; Zatorre et al., 1998; Keenan et al., 2001; Wu et al., 2008; Wilson et al., 2009). There may be areas of the left superior temporal cortex that are larger in AP possessors, but the majority of the asymmetry is caused by reduced volume in the right temporal cortex (Zatorre et al., 1998; Levitin & Rogers, 2005).

The right superior temporal cortex, specifically the planum temporale, is found to be smaller in AP possessors (Loui et al., 2011; Jäncke et al., 2012). Since right auditory regions are found to be involved in pitch direction and tone height judgements (judgments relating to how high or low a pitch is) (Johnstrude et al., 2000; Zatorre & Belin, 2001), this may explain why AP possessors score lower than nonpossessors on tone height tests (Takeuchi & Hulse, 1993; Miyazaki, 1988; Deutsch & Henthorn, 2004; Kim & Knösche, 2017).

Unique brain structure and function to maximize efficiency

AP pitch perception is a quick and involuntary process, so the involved parts of the brain must adapt to be as efficient as possible (Levitin & Rogers, 2005). AP possessors tend to have greater cortical myelination in the right planum polare, especially in the middle depth of the cortex (Loui et al., 2011; Kim & Knösche, 2016). Additionally, regions across both hemispheres, particularly in the superior temporal gyri, also have increased cortical thickness (Dohn et al., 2015). These regions are often found to be involved with assigning pitch names. (Zatorre & Belin, 2001; Wu et al., 2008). This increases the speed of action potentials, allowing pitch perception for AP possessors to be as quick and automatic as it is.

AP posessors have an increased interhemispheric cooperation and a greater spatial extent of activation (Hirose et al., 2004; Wu et al., 2008). This means that the brain can recruit different regions more efficiently when perceiving pitch. Possessors exhibit higher activation of the left planum temporale and heightened resting-state connectivity between the right planum polare, bilateral STSs, and the left planum polare (Ohnishi et al., 2001; Kim and Knösche, 2017). This keeps the brain primed to process pitch information efficiently, explaining how AP possessors can name notes quickly and effortlessly.

Conclusion

In this review, we discussed the unique brain function and anatomy of AP possessors. During listening and pitch identification tasks, an AP possessor will automatically take individual pitches and compare them to a pitch template in long-term memory to name them, while a nonpossessor would need to store the pitch in working memory long enough to hear a reference pitch and deduce the name then. Because of this, AP possessors tend to have greater cortical myelination and interhemispheric cooperation to increase the speed of this process. Another feature is an exaggerated bilateral leftward asymmetry due to a smaller right temporal cortex.

Because AP is a rare phenomenon, sample sizes are not ideal and limited research exists on this topic. Not only do AP possessors make up only 4% of Brazilian music students (Carden & Cline, 2019), but current studies are almost all focused on AP in the context of Western music. For researchers, further investigation into the specific attributes of sound that are perceived as pitch chroma would aid in understanding the function of the temporal lobe more thoroughly. There is evidence that the lateral asymmetry associated with AP exists before birth (Witelson & Pallie, 1973), suggesting a genetic/epigenetic component of AP development. Studies into this and the critical period in which it occurs would be useful in understanding early aural development. For musicians, studies into the possibility of AP in other tuning systems could narrow down environmental factors in AP development. Research on this topic could reveal practices to help prevent the issue of AP categories shifting with age (Baharloo et al., 1998). This study identified key regions of the brain responsible for AP, and future work will shed more light on AP development and musical/scientific applications.

References

1. Baharloo, S., Service, S. K., Risch, N., Gitschier, J., & Freimer, N. B. (2000). Familial aggregation of absolute pitch. American Journal of Human Genetics, 67, 755–758. doi:10.1086/303057
2. Barker, D., Plack, C. J., and Hall, D. A. (2012). Reexamining the evidence for a pitch-sensitive region: a human fMRI study using iterated ripple noise. Cereb. Cortex 22, 745–753. doi:10.1093/cercor/bhr065
3. Bermudez, P., & Zatorre, R. J. (2005). Differences in gray matter between musicians and nonmusicians. Annals of the New York Academy of Sciences, 1060, 395–399. doi:10.1196/annals.1360.057
4. Burns, E. M. (1999). Intervals, scales, and tuning. In D. Deutsch (Ed.), The psychology of music (2nd ed., pp. 215–264). Academic Press.
5. Carden, J., & Cline, T. (2019). Absolute pitch: Myths, evidence and relevance to music education and performance. Psychology of Music, 47(6), 890–901. doi:10.1177/0305735619856098
6. Deutsch, D., & Henthorn, T. (2004). Absolute pitch, speech, and tone language: some experiments and a proposed framework. Music Percept. 21, 339–356. doi:10.1525/mp.2004.21.3.339
7. Dohn, A., Garza-Villarreal, E. A., Chakravarty, M. M., Hansen, M., Lerch, J. P., & Vuust, P. (2015). Gray- and white-matter anatomy of absolute pitch possessors. Cereb. Cortex 25, 1379–1388. doi:10.1093/cercor/bht334

8. Gaab, N., Gaser C., Zaehle, T., Jancke, L., Schlaug, G., (2003). Functional anatomy of pitch memory—an fMRI study with sparse temporal sampling. NeuroImage, 19(4). doi:10.1016/S1053-8119(03)00224-6.
9. Griffiths TD, Warren JD. (2002). The planum temporale as a computational hub. Trends Neurosci. (7):348-53. doi:10.1016/s0166-2236(02)02191-4
10. Hedger, S. C., Heald, S. L. M., & Nusbaum, H. C. (2013). Absolute Pitch May Not Be So Absolute. Psychological Science, 24(8), 1496-1502. doi:10.1177/0956797612473310
11. Jäncke, L., Langer, N., and Hänggi, J. (2012). Diminished whole-brain but enhanced peri-sylvian connectivity in absolute pitch musicians. J. Cogn. Neurosci. 24, 1447–1461. doi:10.1162/jocn_a_00227
12. Johnsrude, I.J., Penhune, V.B., Zatorre, R.J., (2000). Functional specificity in right human auditory cortex for perceiving pitch direction. Brain 123:155–163 doi:10.1093/brain/123.1.155
13. Keenan, J. P., Thangaraj, V., Halpern, A. R., & Schlaug, G. (2001). Absolute pitch and planum temporale. Neuroimage 14, 1402–1408. doi:10.1006/nimg.2001.0925
14. Kim, S.-G., & Knösche, T. R. (2016). Intracortical myelination in musicians with absolute pitch: quantitative morphometry using 7-T MRI. Hum. Brain Mapp. 37, 3486–3501. doi:10.1002/hbm.23254
15. Kim, S.-G., & Knösche, T. R. (2017). On the Perceptual Subprocess of Absolute Pitch. Frontiers in Neuroscience, 11. doi:10.3389/fnins.2017.00557
16. Levitin D. J. (1994). Absolute memory for musical pitch: evidence from the production of learned melodies. Perception & psychophysics, 56(4), 414–423. doi:10.3758/bf03206733
17. Levitin, D. J., & Rogers, S. E. (2005). Absolute pitch: Perception, coding, and controversies. Trends in Cognitive Sciences, 9(1), 26–33. doi:10.1016/j.tics.2004.11.007
18. Loui, P., Li, H. C., Hohmann, A., & Schlaug, G. (2011). Enhanced cortical connectivity in absolute pitch musicians: a model for local hyperconnectivity. J. Cogn. Neurosci. 23, 1015–1026. doi:10.1162/jocn.2010.21500
19. Miyazaki, K. (1988). Musical pitch identification by absolute pitch possessors. Percept. Psychophys. 44, 501–512. doi:10.3758/BF03207484
20. Oxenham A. J. (2012). Pitch perception. The Journal of neuroscience : the official journal of the Society for Neuroscience, 32(39), 13335–13338. doi:10.1523/JNEUROSCI.3815-12.2012
21. Petrides M. (1995). Impairments on nonspatial self-ordered and externally ordered working memory tasks after lesions of the mid-dorsal part of the lateral frontal cortex in the monkey. The Journal of neuroscience: the official journal of the Society for Neuroscience, 15(1 Pt 1), 359–375. doi:10.1523/JNEUROSCI.15-01-00359.1995
22. Rauschecker, J.P. (2015), Auditory and visual cortex of primates: a comparison of two sensory systems. Eur J Neurosci, 41: 579-585. doi:10.1111/ejn.12844

23. Rauschecker, J. P., & Tian, B. (2000). Mechanisms and streams for processing of "what" and "where" in auditory cortex. Proceedings of the National Academy of Sciences of the United States of America, 97(22), 11800–11806. doi:10.1073/pnas.97.22.11800
24. Schlaug, G., Jäncke, L., Huang, Y., & Steinmetz, H. (1995). In vivo evidence of structural brain asymmetry in musicians. Science 267, 699–701. doi:10.1126/science.7839149
25. Suriadi, M. M., Usui, K., Tottori, T., Terada, K., Fujitani, S., Umeoka, S., Usui, N., Baba, K., Matsuda, K., & Inoue, Y. (2015). Preservation of absolute pitch after right amygdalohippocampectomy for a pianist with TLE. Epilepsy & Behavior, 42, 14–17. doi:10.1016/j.yebeh.2014.10.025
26. Takeuchi, A. H., & Hulse, S. H. (1993). Absolute Pitch. Psychol. Bull. 113, 345–361. doi:10.1037/0033-2909.113.2.345
27. Ward, W., & Burns, E. (1982). Absolute pitch. The Psychology of Music, ed D. Deutsch, 265–298
28. Warren, J. D., Uppenkamp, S., Patterson, R. D., & Griffiths, T. D. (2003). Separating pitch chroma and pitch height in the human brain. Proceedings of the National Academy of Sciences, 100(17), 10038–10042. doi:10.1073/pnas.1730682100
29. Wilson, S. J., Lusher, D., Wan, C. Y., Dudgeon, P., & Reutens, D. C. (2009). The neurocognitive components of pitch processing: insights from absolute pitch. Cereb. Cortex 19, 724–732. doi:10.1093/cercor/bhn121
30. Wu, C., Kirk, J.I., Jeff P.H., & Vanessa, K.L. (2008). The neural networks involved in pitch labeling of absolute pitch musicians. NeuroReport 19(8):p 851-854. doi:10.1097/WNR.0b013e3282ff63b1
31. Zatorre R. J. (1989). On the representation of multiple languages in the brain: old problems and new directions. Brain and language, 36(1), 127–147. doi:10.1016/0093-934x(89)90056-4
32. Zatorre, R. J., & Belin, P. (2001). Spectral and temporal processing in human auditory cortex. Cerebral cortex 11(10), 946–953. doi:10.1093/cercor/11.10.946
33. Zatorre, R. J., Perry, D. W., Beckett, C. A., Westbury, C. F., & Evans, A. C. (1998). Functional anatomy of musical processing in listeners with absolute pitch and relative pitch. Proceedings of the National Academy of Sciences of the United States of America, 95(6), 3172–3177. doi:10.1073/pnas.95.6.3172