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Pitch perception preference in children with or without formal musical education*

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Abstract

Among the mental functions recruited by music, timbre processing is possibly one of the most interesting, as it exemplifies the perceptual constancy that allows recognition of regularities in the environment. The objective of the present work was to investigate the musical perception of children with formal music education and the prevalence of fundamental and spectral listeners based on the differential perception of complex tones. Thirty children between 10 and 15 years old participated, who responded to 48 pairs of tones, in which the second tone should be judged as ascending or descending. The participants' responses allowed the calculation of an index of pitch perception preference (Δp). The results show that the Control Group presented Δp closer to zero than the Musicians Group, both with normal distribution. Therefore, musicians and nonmusicians have subtle differences in the perception of complex tones, with a preference for fundamental listeners among the musicians investigated.

Keywords: music, auditory cortex, auditory perception, pitch perception, timbre perception

Preferência de percepção tonal em crianças com ou sem educação musical formal

Resumo

Dentre as funções mentais recrutadas pela música, o processamento de timbre é possivelmente um dos mais interessantes, pois exemplifica a constância perceptual que permite reconhecimento de regularidades no ambiente. O objetivo do presente trabalho foi investigar a percepção musical de crianças com educação formal em música e a prevalência de ouvintes sintéticos e analíticos com base na percepção diferencial de tons complexos. Participaram trinta crianças entre 10 e 15 anos, que responderam a 48 pares de tons, nos quais o segundo tom deveria ser julgado como ascendente ou descendente. As respostas dos participantes permitiram o cálculo de um índice de preferência de percepção tonal (Δp). Os resultados mostram que o Grupo Controle apresentou Δp mais próximo a zero do que o Grupo Músicos, ambos com distribuição normal. Logo, músicos e não-músicos têm diferenças sutis na percepção de tons complexos, com predominância de ouvintes sintéticos para os músicos investigados.

Palavras-chave: música, córtex auditivo, percepção auditiva, percepção da altura sonora, percepção de timbre

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Introduction

Cognition may be defined as a set of mental processes or mechanisms for gaining knowledge and processing and storing information about the environment, including thought. Shettleworth (2010) adds the necessity of representing all surrounding stimuli and storing data as the core of cognition. Through cognitive processes, other phenomena arise as attention, memory, percepção, decision-making, and reasoning

From this definition of cognition, one can infer the meaning of musical cognition, an expression found in a lot of articles related to formal music training (Beyer, 2014) and the impact of other functions on musical processing, like speech and its competence in children (Zuk et al., 2013), sound processing in general (Nan et al., 2018), and working memory (Vuvan et al., 2020).

Thus, all these subjects can be related to music training and the music itself. Stalinski and Schellenberg (2012) state that "music is often a complex stimulus, with tones that vary over time in pitch, duration, amplitude, and timbre." Because of this complexity, musical practice requires daily training, sustained focus, melody memorization, and learning of various musical structures (Schellenberg, 2004).

It is understood, then, that music education involves several skills, and there is evidence that it causes an increase in IQ (Schellenberg, 2004; Kaviani et al., 2014). Kaviani et al. (2014) provided 12 seventy-five-minute extracurricular music lessons for 30 children aged between 5-6 years old, who were later compared to another 30 children who did not have music lessons. All of them were tested before and after the class period with an intelligence scale (Tehran-Stanford-Binet Intelligence Scale, TSB). Results have shown increased IQ, specifically on the verbal reasoning and short-term memory subtests. These results could be involved in structural changes of the brain gray matter, already highlighted in the literature (e.g., Gaser & Schlaug, 2003), and allow speculation on the long-term effects of formal music training.

The musical practice embraces the development and enhancement of processes like sensitivity, creativity, listening, perception, attention, and imagery, in addition to enabling autonomous knowledge construction and growth of individual responsibility (Figueiredo, 2012), features that are important to child development. As already pointed out, such improvement can be seen in verbal memory tests, where children with music training exhibit better results than children without training. Furthermore, among child musicians, those who continue musical training further improve their verbal memory compared to those who discontinue formal music study (Ho et al., 2003).

Brain organization allows specific skills in children, and according to Levine (2003), it can be organized or divided into systems, improving comprehension. Ilari (2003) skillfully arranges these systems in attention, memory, language, spatial orientation, sequential ordering, motor, superior thought, and social cognition. She also argues that all these systems can be combined

Among the mental functions recruited by music, timbre processing is arguably one of the most interesting. Timbre recognition involves the problem of perceptual constancy — the cognitive capacity that allows environment perception as stable, notwithstanding changes in sensorial stimulation (Zatorre, 2005). Through timbre, musical instruments can have octaves - regular intervals of musical notes that double in frequency with each new octave. Similarly, timbre allows distinction among musical instruments, despite them playing the same musical note.

It is important to emphasize that timbre processing is not negligible, even outside the music realm. Timbre perception grants sound source recognition (Samson, 2003). Also, newborn babies discriminate their mother's voice from others (Trehub & Hannon, 2006), and Zatorre (2005) highlights that, in nature, periodic sounds are almost exclusively produced by animals and, therefore, are important for species recognition and predator detection.

Bendor and Wang (2005) have shown, in marmoset monkeys, auditory cortex neurons that respond to both pure tones and missing fundamental harmonic complex sound with the same f_0, but not only tonotopically. These neurons could activate to different instrument timbres (even though entirely different frequency spectra characterize them) and pitch with or without f_0. Neurons recorded by the authors are located near the anterolateral border of the primary auditory cortex (A1). More recently, Bendor, et al. (2012) have also shown that tonality processing involves a dual mechanism relating to temporal envelope cues and the frequency spectrum itself, so the first process is privileged for lower sounds and with more harmonics, and the second, for higher sounds and with fewer harmonics.

Wang (2013) argues that these competencies attest to selection by neural circuits capable of responding to harmonicity, something ubiquitous in nature, according to the author. For Plack (2010), harmonicity would be fundamental for the emergence of consonant music. The findings of Bendor and Wang (2005) and Bendor et al. (2012) could even explain the missing fundamental processing, a concept explored since the 1970s by Terhardt (1974), which still intrigues researchers (Zatorre, 2005). Terhardt (1974) develops the concept of “virtual pitch” to characterize the missing fundamental and illustrates that its processing would involve the same perceptual completion already known for the visual system, as in Kanizsa's triangle.

The author also describes that the perception of the pitch could be done in two ways: an analytical or spectral mode — which would involve the predominant perception of individual timbre frequencies and higher harmonics, and a synthetic or fundamental mode — with the predominant perception of the music’s envelope fundamental, whether present in the frequency spectrum or missing. This suggestion is similar to that made by Helmholtz (1895), who characterized the spectral or fundamental modes as a function of the listener's attention level.

Schneider et al. (2005a, but also in Benner et al., 2017), on the other hand, argue that spectral and fundamental listeners reflect a pitch perception preference based on differences in gray matter volume and electrophysiological activity of Heschl's gyrus (essentially A1, Brodmann areas 41 and 42). According to them, the distribution of a population sample regarding the presentation of ambiguous tone pairs (in which the second tone can be perceived as either ascending or descending) would be bimodal but not normal. Schneider et al. (2005a) presented 144 tone pairs to musicians and nonmusicians. Participants were asked to judge whether the second tone of the pair was ascending or descending relative to the first. The answers allowed the calculation of a "pitch perception preference index" (δ_p), which defined each volunteer's classification as fundamental or spectral listeners.

There is no consensus in the literature, therefore, if the different modes of pitch perception are related to innate/ontogenic aspects of the Heschl gyrus or the attentional level, or other attributes of the subject's perception. Furthermore, the literature seems to have not yet investigated this issue, specifically in children. Enlighten whether or not there are such distinctions in auditory perception and whether it is possible to establish a bimodal distribution between fundamental and spectral listeners can contribute to the understanding of essential aspects of musical cognition and contribute to a still young area of cognitive science in addition to generating insights both for the musical competences themselves in humans, but also for aspects of phonological and auditory processing (Honing et al., 2015).

Thus, the objective of the present work was to investigate the pitch perception preference of children with formal music training on a tonal instrument and the prevalence of fundamental and spectral listeners concerning children without formal music training.

Methods

Participants and procedure

The present work was analytical, experimental, and transversal. The National Research Ethics Committee approved all procedures. A sample of 33 children between 10 and 15 years old was invited to participate, constituting a Musicians Group - children with at least one year of formal music training (up to ten years), and a Control Group. These children had no previous contact with a musical instrument or music lessons. Three participants were excluded after declaring a lousy night of sleep the night before the test - less than four hours - and one was under psychotropic medication. The final sample was 29 participants (Control: n=14 and Musicians: n=15).

Participants were presented with 48 pairs of ambiguous, complex tones - composed of two, three, or four pure tones — to evaluate if the second tone was ascending or descending about the first (see Schneider et al., 2005a). Presentations were performed in a controlled environment, from the same speaker to all participants simultaneously by the group. Given the complex tones' simplicity, environment acoustic interferences were negligible. Each tone was presented for 500 ms, with 500 ms interval to the second tone, two times in a row, with 1000 ms interval between the first and second presentation of the pair. All 48 stimuli were presented in the same order to both groups.

Tone pairs are ambiguous because the harmonics (f_{SP}) variation from the first to the second tone causes a change in the perception of the missing fundamental (f_0). That is, when the frequency of the harmonics goes up (except the last harmonic, kept constant), f_0 is perceived as descendent and vice versa. Responses were made on paper, with participants judging if the second tone was ascending or descending concerning the first one. After the initial explanation, the total time of the test was under five minutes.

Statistical analysis

An "index of pitch perception preference" (δ_p) (Schneider et al., 2005a) was calculated after participants' responses, identifying if they had processed preferably f_0 or f_{SP} of the tone pairs. The δ_p is calculated as:

$\delta_p = (nF_0 - nF_{SP}) / (nF_0 + nF_{SP})$, where:

- nF_0: Number of times the participant listened to f_0.
- nF_{SP}: Number of times the participant listened to f_{SP}.

An analysis of variance (ANOVA) was run to compare δ_p with musical expertise (musician vs. nonmusician) between subjects. The Omega squared (ω^2) indicator was used to estimate effect size, been considered insignificant when $\omega^2 < 0{,}01$, small when $0{,}01 \leq \omega^2 < 0{,}06$, medium to $0{,}06 \leq \omega^2 < 0{,}14$, and large to $\omega^2 \geq 0{,}14$ (Goss-Sampson, 2020).

Data was also presented about a group's distribution of the δ_p to all subjects to comprehend if the δ_p distribution obeys a Gauss or binomial distribution, as in Schneider et al. (2005).

Results

The average age of the Musicians Group was 13,133±1,506, and for the Control Group, 13.357±1.499, with no differences ($F_{1,27}$=0.161, p=0.692). The average formal music training time for the Musicians Group was 5.00±2.32 years.

Results showed that Musicians had δ_p closer to zero, with Gauss distribution of the sample, probably because they responded indistinctly to the f_0 or the f_{SP}. ANOVA revealed a small effect between the δ_p of musicians and nonmusicians ($F_{1,27}$=1.602, p=0.216, ω^2=0.020). The average value of δ_p was -0.289 ± 0.387 for musicians and -0.146 ± 0.177 for the Control Group. The distribution of the subjects concerning δ_p is shown in Figure 1.

Figure 1 also shows that δ_p results are more variable for the musicians than for the nonmusicians (Levene's test for equality of variances: p=0.005, suggesting that variance is, indeed, different), besides that, there were more subjects with an index below -0.5 (fundamental listeners) among the musicians than on Control Group, that concentrates around δ_p=0.

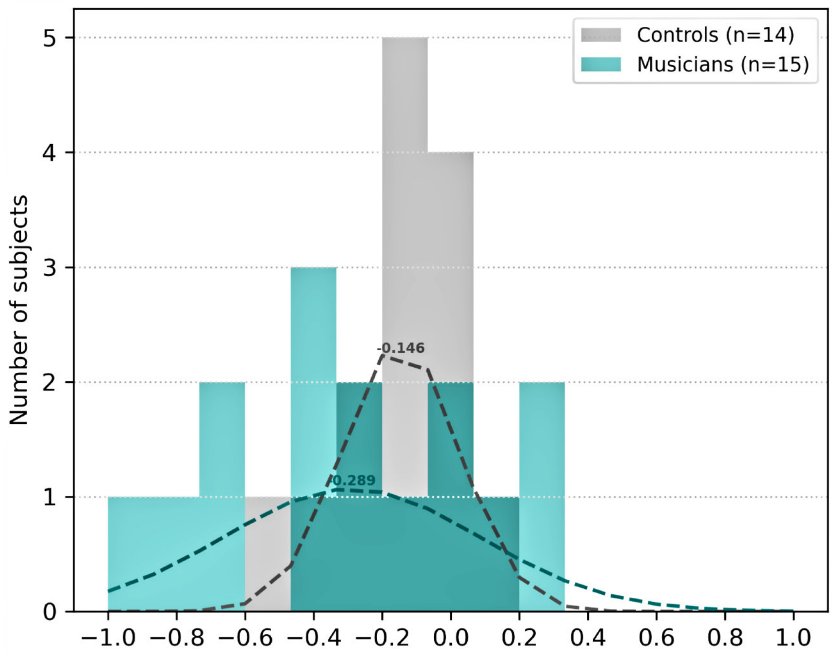
Discussion

Our findings suggest that children without formal music training have a Gaussian distribution of the index of pitch perception preference (δ_p) and that an average of five years of music training could shift this δ_p towards the fundamental side of the spectrum. We did not find a binomial distribution of δ_p in our sample, although musicians' distribution is wider than that of nonmusicians. This finding contrasts with the results of Schneider et al. (2005a) but adds to similar results in the literature.

Schneider et al. (2005a) do not specify the δ_p by group (musicians or nonmusicians). Still, they just present δ_p distribution for 420 tested subjects, mostly musicians, including 125 professional musicians from the Royal Liverpool

Figure 1

Distribution of the index of pitch perception preference (δ_p) in children with or without formal music training.



Philharmonic Orchestra (RLPO). In a subgroup of 87 subjects, the authors used MRI to find morphological differences at the Helschl's gyrus (HG). Interestingly, in this subgroup, the δ_p distribution of 20 nonmusicians follows a Gaussian curve, maybe with a slight bias towards fundamental listeners, similar to our results (this finding is not explicitly reported by Schneider et al., 2005, but it is seen on Figure 5 in the article).

The same binomial distribution is not reported by Schneider et al. (2005b). In this work, the authors evaluate the average δ_p regarding musicians' instruments, and again they relate the HG structural differences to pitch perception preference. Considering the different instruments represented, musicians are distributed by all the δ_p spectrum. For nonmusicians (n=54), δ_p distribution was again Gaussian and averaged close to zero.

Both works (Schneider et al. 2005a, 2005b) report that fundamental listeners have the greater cortical volume at the left lateral HG (lHG), and spectral listeners have the opposite asymmetry, with greater gray matter volume towards the right lHG. Particularly in Schneider et al. (2005b), the perceptual/morphological asymmetries are related to the instruments played by each musician. While f_0 listeners prefer instruments like piano, percussion, guitar, trumpet, or flute, with sharp and impulsive tones, f_{sp} listeners prefer string, brass, or wind instruments and singing, with sustained tones and (more) melodic usage.

In this sense, it is important to note that the musicians in the present work are mainly string players (all violinists, except for one cellist), but different from Schneider's et al. (2005b) findings, these tend to f_0 listeners. This difference may be a particularity of children still under formal music training. Schneider et al. (2005b) do not disclose the musicians' music training time. Still, considering that many of them were professional musicians, including members of the

RLPO, they likely had more training than the included sample. Schneider et al. (2005a) mention at least ten years of musical practice to its participants, and these articles probably shared the same sample, considering the same publication's date and mention of RLPO musicians.

If the alterations related to musical competence are regarded and extensively reported in the literature (Zatorre, 2003; Peretz & Zatorre, 2005; Hyde et al., 2009; Schlaug, 2015; Steele & Zatorre, 2018; Grégoire & Poulin-Charronnat, 2019; Hennessy et al., 2020; Groussard et al., 2020; Møller, 2021; Kragness et al., 2021; Olszewska et al., 2021, to cite a few), the neuroplasticity effects are probably proportional to the music training time.

Interestingly, Zoellner et al. (2019) argue that the HG contains, both in children and in adults, regions with thinner gray matter that would correspond to A1 since these slender regions are the first ones to show an evoked potential after a sound on the environment. The increase in HG shown by Schneider et al. (2005a, 2005b) must be a product of the timbre processing necessity promoted by music, as defended by Zoellner et al. (2019). Yet, Seither-Preisler et al. (2014) have shown functional alterations on HG of 7 to 9 y.o. children with formal music training, specifically, the authors showed more excellent synchronization of the activity in this region among brain hemispheres.

Hyde et al. (2009) also investigated children (average 6 y.o.) to show differences in the primary motor cortex, HG, and corpus callosum after fifteen months of extra-class keyboard lessons about an age-matched control group. Given the absence of previous differences between the groups (before the music lessons), the authors concluded that music could speed the development of these specific regions and, maybe, promote neuroplastic differences that persist into adulthood, especially in professional musicians. For example, Gaser and Schlaug (2003) show gray matter differences among musicians and nonmusicians, in addition to establishing a correlation between long-term skills and the time of musical practice. Similarly, Steele and Zatorre (2018) argue in favor of neuroplasticity induced by music learning. They mention Bengtsson et al. (2005), who verified alterations of association fibers (white matter) in the brain. Steele and Zatorre (2018) also defend that alterations could be correlated with the time of previous musical studies.

Even more striking, Kim et al. (2020) modified the melody of Mozart's *12 Variations* KV 265, well-known as *Twinkle Twinkle Little Star Variations*, an English lullaby. They presented the original music and the modified versions to 25 participants without formal music training. Results of magnetoencephalography imaging (MEG) showed that the modified versions induced acute alterations of the communication between the left inferior frontal gyrus and the right HG, important areas for processing the music's melody. Therefore, it seems clear in the literature that music promotes functional and structural differences in short and long-term periods. It is also remarkable that Rus-Oswald et al. (2022) have shown that some of these improvements remain in musicians over 70, including functional particularities in response to musical stimuli compared to younger musicians. More experienced musicians activate more diffuse neural networks in response to music, including more associative regions.

Seither-Preisler et al. (2007) also investigated musicians and nonmusicians in a task with ambiguous pairs of tones. The authors classified musicians among professionals and amateurs based on formal music training and time of weekly practice. They hypothesized that musicians would better use the missing fundamentals to judge the tones regarding perceptual completion (Terhardt, 1974). Results showed that professional musicians had higher scores in the task, followed by amateur musicians and, lastly, nonmusicians. It is essential to notice that the participants were primarily pianists, which supports Schneider's et al. (2005b) statement that pianists are f_0 listeners, with δ_p close to 0.3. Nonetheless, scores used by Seither-Preisler et al. (2007) are different from Schneider's δ_p and our work, preventing further comparisons. However, our sample exhibits most musicians as f_0 listeners regardless of instrument.

It is important to point out that Seither-Preisler et al. (2007) present three hypotheses for the group's differences. The first argues that music training is important because of the enhancement of pitch perception and neural representation provoked by musical expertise. This hypothesis is the author's explanation choice. Although there are a lot of works that, indeed, support functional adaptations that take place as enhancement of cortical representation after music training, this evidence is invalid regarding Schneider's asymmetries of HG and its correlations with δ_p (Schneider et al., 2005a). Combined, musicians from various instruments have an average δ_p close to zero precisely because of the musicians on both sides of the spectrum (f_0 and f_{sp} listeners). It would be important for new investigations to replicate the Auditory Ambiguity Test used by the authors, with its scoring system, on more musicians and form different instruments than the original ones.

A second hypothesis would be that the differences stem from genetic/congenital factors related to musical aptitude. Still, the authors argue that musical aptitude is not exactly related to learning a musical instrument or being a musician. In support of that, though, Kragness et al. (2021) showed that the differences in musical competence are stable through time and barely influenced by musical training. It is important to note that this work evaluated specific executive functions but no structural differences from others (e.g., Hyde et al., 2009). Therefore, there is evidence that music can promote changes that previously did not exist.

Finally, Seither-Preisler et al. (2007) argue that the difference in pitch perception preference could be due to variations in the subject's attention to the tones. Thus, musicians would focus on the relevant f_0 and nonmusicians on the physical attributes of the tones. This is the same hypothesis originally made by Helmholtz (1895). It is impossible to endorse just one of these hypotheses regarding our results. Just as there are consistent arguments for each of these ideas posed by Seither-Preisler et al. (2007), all of them could have interacted with the differences among musicians and nonmusicians in the processing of the ambiguous tones: the genetic aspects can predispose differences in HG and consequently, to the capacity of learning a musical instrument; the changes by neuroplasticity could exacerbate even more these differences, and at last, the attentional focus could also change tone perception, and accordingly, the responses to the tones' pairs.

No specific control was made to these aspects in this or other works. Genetic aspects that can influence tone perception or timbre are unknown. Structural and functional changes in music are largely known and expected among formally trained musicians and were reported herein. But once more: cortical representation changes, for example, have been known for over twenty years (Elbert et al., 1995; Pantev et al., 2001). And regarding the attentional level of the participants, attention was requested by the experimenters. Future work could try to modulate attentional level with a concurrent task, forcing attention divide, or simply presenting different instructions to the subjects on responding to the pair of tones, trying to evaluate if attentive issues tend to process the spectral cues and, inattentive ones, to the missing fundamental, as proposed by Helmholtz (1895).

A fundamental listeners' sample, both with musicians and nonmusicians, can also be found in the work of Postma-Nilsenová & Postma (2013). However, comparisons between them were out of the scope of the authors. There is no mention of the musicians' instruments either. Eighty-eight participants were investigated with pairs of complex tones, similar to other works cited above, and the same δ_p calculation was made. Results show a Gaussian distribution of the δ_p, with a predominance of f_0 listeners in the sample, including about half who declared themselves professional musicians or with high musical proficiency. It is worth noticing, however, that the authors have defined participants with $\delta_p=1$ as f_0 listeners and $\delta_p=-1$ as f_{sp} listeners. The reason for the inversion of Schneider's original criteria is unclear, although the δ_p formula was the same. Despite the absence of a distinction between musicians and nonmusicians in their work, Postma-Nilsenová and Postma's (2013) report of mainly f_0 listeners, even with half of the sample declaring high musical proficiency, suggest results similar to ours.

Compared to the above articles, our work differs in investigating the pitch perception preference in children undergoing formal music training but not in professional musicians with more musical expertise. The majority of the sample is fundamental listeners, in line with the work of Seither-Preisler et al. (2007) and Postma-Nilsenová & Postma (2013) but differing specifically from string musicians investigated by Schneider (2005b). But even these authors recognize that the preference of tonal perception is not necessarily fixed and is even influenced by factors such as the style of musical performance. According to them, a pianist with $\delta_p<0$ (f_0 listener) may prefer to play your instrument with virtuosity and complex rhythmic patterns. In contrast, another one with $\delta_p>0$ (f_{sp} listener) could prefer slower music and focus more on the melodic and timbre aspects of the song.

Therefore, further investigations are needed to understand the variability related to pitch perception preference and the effects caused by musical training in this functional particularity. It is important to emphasize that the works by Schneider et al. (2005a, 2005b) remain the only ones to find a binomial distribution for the index of pitch perception preference.

Concluding remarks

In this way, we can say that musicians and nonmusicians do indeed have differences in the perception of complex tones, with a pitch perception preference predominantly as fundamental listeners for the musicians of the selected sample, children still in formal musical training on a string instrument (violinists). In addition, all participants are distributed according to the Gaussian curve along the index of pitch perception preference, musicians or nonmusicians.

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