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Investigating the pitch discrimination structure for low and high frequency notes in Persian-speaking children

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Abstract

Pitch discrimination is a manifestation of sound frequency perception and is defined as an auditory perception that can arrange sounds on a scale from low to high. Pitch discrimination aptitude is an acquired process and as with any other process can be affected by personal and environmental conditions. The pathway and index of these changes are the goals of the present study. In this study pitch discrimination of 75 children, including 37 girls and 38 boys at the age of 8-12 was evaluated by comparing the pitch ratios. The pitch threshold is the minimum distance in which a child can correctly distinguish two successive notes. These indexes were obtained for four notes of musical instruments and voices that are most frequent. Average pitch discrimination for the four notes under study was estimated to be fewer than six semitones and slightly more than four semitones; however, for notes with lower fundamental frequencies, this threshold showed to have higher quantities. The structure of pitch discrimination for sounds with low fundamental frequency is distinct from the sounds with high fundamental frequencies, and unlike treble sounds, at least in childhood, pitch discrimination of bass continues to grow and develop.

Keywords: *Pitch, Discrimination, Children, Note, Semitone*

Introduction

Studies carried out in the field of sound stimuli discrimination so far signify fundamental mechanisms since birth in children[1]. Researchers showed that auditory information discrimination exists in children but with the difference that this age group needs higher acoustic characteristics for discrimination to be allowed to occur[2]. Benasich & Tallal (2002) reported that children at six to nine months of age are capable of rapid frequency transmittance upward or downward, even though the adults can not appreciate this level. They showed that the rapid processing capabilities of infants are the best predictor of language performance at 24 months of age[3]. Nittrouer et. al (2009) showed that children at seven, before being taught, can perceive linguistic patterns from the spectral structure only based on the signals with preserved amplitude structure[4]. Pitch discrimination is a demonstration of sound frequency perception and is defined as an auditory perception that can arrange sounds on a scale from low to high[5]. Pitch and frequency, while being physically dependent on each other, are two distinct concepts. When a sound auditory frequency is doubled, we perceive a linear increase in the pitch. Hence, octave, semitone, and cycle/second (CPS) instead of Hertz (Hz) are the units used for pitch. An octave is defined as a distance between one tone and another tone with doubled frequency and is expressed in a logarithmic scale; however, each semitone index is equal to one-twelfth of one octave[6]. Maria Kulick et. al. in 2016, while designing an algorithmic tool of pitch discrimination for preschool children, found that preschool children between the ages of three to four exhibited a characteristic improvement in pitch discrimination in the pitch discrimination test (PDT). Accordingly, they concluded that the pitch discrimination test is a more convenient and efficient tool for frequency discrimination algorithms in preschool children[7]. The tool, of course, consists of 500, 1000, 2000, and 3000 Hertz, of which the time represented was 100 milliseconds and the interval 300millisecond. On the other hand, studies by Thompson et. al. (1999) showed that the frequency discrimination of short tones may be developmental and may not come to fruition before seven years old[8]. Therefore, as expected, to study any full frequency discrimination function and the relevant characteristics, namely pitch discrimination, we must wait until age seven and older. Pitch discrimination by tonal stimuli is associated with intelligence through signal demonstration skills or sensory analysis. The performance of some psychological discrimination task are clearly associated with intelligence potential and any diagnosis of pitch discrimination must account for intelligence[9]. Albeit over time there could be various alterations of intensity and vocalization, the most salient acoustic index of tones is the fundamental frequency and pitch, too, is used as a signal for tonal discrimination of sounds described and in perception

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tests, both have been verified tests using natural and competing speech stimuli[10]. The ability of pitch analysis is an acquired process[11]. Based on the data available, neural subsets of pitch perception play a role in the process of verbal tones forming through linguistic experiences. Distinct sensitivity between the pitch height in responses received from the cerebral cortex and following frequency responses might be an indicator of a transmission from a temporal coding representation of a pitch to a Firing-rate coding representation in the cerebral cortex[12]. According to the study results various characteristics of a pitch can be processed in distinct pathways and elicit variable responses[13]. Studies of the frequency following responses demonstrate that the auditory system encodes pitch at the surface of neural fibers in the form of a phase-dependent process. Albeit the psychophysical evidence emphasizes Peripheral Place Code, the precision of phase lock is decreased while ascending the neuronal pathways and central auditory nerves, and at the level of stem cell and higher, the nature of coding of Firing Rate based code representatives is altered. In the brain stem or auditory cortex, the personal information of an individual is combined to portray a general manifestation of pitch and activate a specific area for pitch perception in the Secondary Auditory Cortex[14]. In general, parametric alterations of pitch manifestations enable us to separate the pitch-based neural activity – which shows that primarily this is the general sensory processes of the body – from Language-Dependent (Linguistic) Neural Activity. Differences in the sensitivity to pitch manifestations in the brain stem and cerebral cortex may signify that there could be transmission in the nature of pitch processing in the brain[11].

In this research, we intend to investigate the functional characteristics of pitch discrimination by evaluating and comparing pitch discrimination thresholds in notes with different basic frequencies during the ages of 8 to 12 years.

Materials and Methods

Participants

In assessing the pitch discrimination, 75 children participated in the study; they had an average age of 10.59±1.42 including 38 boys and 36 girls, with average ages of 10.84±1.39, and 10.32±1.42, respectively. There was no significant difference between the ages of the boys and the girls in terms of statistical average (P=0.110). All the children had a normal auditory threshold (≤ 15dB) within the range of audiometric frequencies and normal speech discrimination scores (≥92%). Also, the participants did not have any history of neurological and psychological diseases and the dominance of the right hand in all subjects was verified through Edinburg Handedness Inventory; further, the subjects did not have any history of long-term hospitalization, surgical intervention, and long-lasting infections of the middle ear. Regarding the Intelligence quota, all cases lay within the normal range (≥85) on Leiter's IQ scale.

Pitch Discrimination Evaluation

There exist various concepts in the process of pitch assessment. Absolute pitch, a rare phenomenon that exclusively belongs to professional musicians, basically is the capability of sound pitch discrimination in the absence of any external reinforcement[15]. Nonetheless, most individuals are capable of coding for one pitch differently than the other pitches, the aptitude which is named the relative pitch. Indeed, except for individuals with Amusia or tone deafness, other people can detect the variations in pitch patterns expressed as "upper_lower" patterns since childhood[16]. Fundamentally, relative pitch discrimination is a process that occurs in the brain stem but absolute pitch discrimination is represented as parallel pathways and the formation of peripheral synapses, as a result of professional occupation[17]. Accordingly, to investigate the capability of pitch discrimination in our study, we specifically utilize the relative pitch discrimination pathway. However, relative pitch discrimination can be accomplished through three training programs:

Pitch discrimination, Odd-one-out, pitch contour[16].

In the process of pitch discrimination, two types of notes are presented to the subject and he or she must hone in on the note with a higher pitch, that is, to identify the higher or lower note[18]. In the odd-one-out approach, the subject must listen to three notes, among which to identify the note that is distinct from the two other notes[19]. Appreciating the pathway of pitch variation is not required in this process. For the pitch contour task, the subject must listen to five notes and identify the direction of pitch variations and the distance between intervals in between[18]. In the present study, we take utilized the pitch discrimination approach. To this end, two notes were represented for the child and he or she must identify the treble note.

The piano is the most common musical instrument. Its tones are most frequently used as stimulates in frequency modulation evaluations to the extent that some of the researchers use the "absolute piano" phrase instead of "absolute pitch"[20]. In this study, we also utilized this instrument for pitch discrimination purposes. Thresholds were rated for four notes [F#3] at 185 Hz, [C4] 262 Hz, [E4] 330 Hz, and [G4] 391 Hz. These sets of notes were designed digitally with a uniform temporal envelope based on the middle note of piano C (262 Hz), and the octave surrounding middle C is the most common octave among the prototypical frequency ranges for western musical instruments and sung voices[13].

Each stimulus lasts for a total of 500ms ± 50ms (Fig.1). The interval between two consecutive notes was set for 1.2 second. In this setting, the first stimulus lasts for 600ms, with 600ms of silence in between, the total time of the second note too will be 600ms. The sounds were recorded digitally at a sampling rate of 44.1 kHz and a quality of 320 kbps[21]. Stimulus intensity was adjusted to the SPL level of 67-68 dB. The provided sounds were in biphasic and simultaneous modes. Sounds were presented using the Beats Studio 2 headphone by Asus Lab Top N43J.

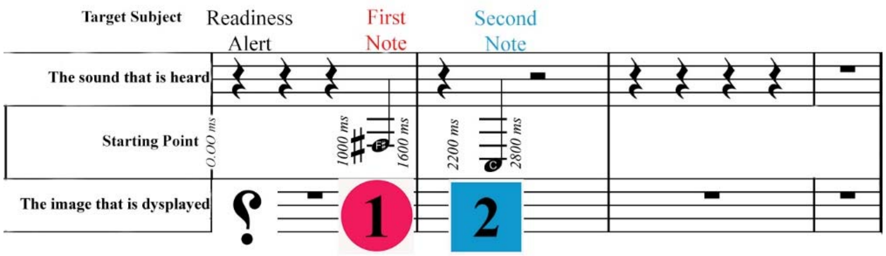

Figure 1: Plan of presented stimuli and their timing. A standby image (?) is displayed for one second before the notes (here: F#3 & C3) are presented. The duration of each note is 600 milliseconds, which are presented at intervals of 600 milliseconds. After the second note is presented, the child has five seconds to respond.

Before representing each pair of notes under study, to aid in prognosis and preparation, a question mark is displayed on the screen for one second and then the notes are represented. At the same time as presenting the first note, a red circle with the number 1 inserted in the middle was shown to the children, and at the same time as presenting the second note, a blue square with the number 2 inserted in the middle was shown to them. They were taught to identify the higher note after hearing the second sound. Following the presentation of two notes, the child had 5 seconds to respond. In case of receiving no response, the respective couple would be removed from the statistical calculations. They could select the desired note by referring to the color, shape, number, or order of the notes. Pairs were presented randomly, and evaluations started from an octave distance. Similar studies have reported that the ability of pitch discrimination, irrespective of any musical training, is lower than one octave[22]. Thus, considering one octave, as an origin to initiate the assessment of pitch discrimination, is expectably a fit index. One octave of the note of interest is the distance of pitch discrimination threshold evaluation from pitch discrimination instruction. To preclude the bias of assessment experience on the results, the notes are randomly selected. For every note under assessment, we initiate by choosing the comparative note with one octave higher. Before starting, the child must be familiar with the assessment content. The training video is initiated using the notes with a four-octave vocal range. The child has to select the higher note within this wide range. After several drills and familiarizing the child with the process, the assessment process is initiated (Fig. 2). One of the features of pitch assessment is the intervention of memory in the process of note retrieval[23]. Therefore, we must constrain the probability of memory intervention in the process. Therefore, each one of the fundamental notes F#3, C4, G4, and E4 are chosen as the fixed note and we initiate the process from a note with a higher pitch above one octave, hence precluding the memorability of the note by virtue of the variability. For instance, the comparative process is commenced from notes E4-E5. These two notes are randomly selected and the child must determine which sound has the higher pitch. Through success at every stage, the tone of interest is reduced by one semitone and the assessment process is carried out again. In case of failure, the tone of interest is increased by one semitone and the assessment is repeated. We proceed with the comparison process until reaching the minimum range in which the child can no longer pass the criteria.

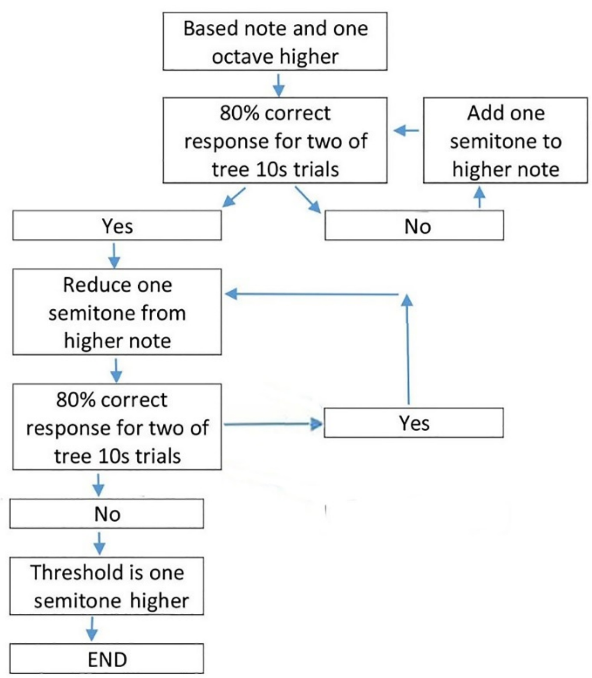

Figure 2: the flowchart of the assessment of the natural threshold of pitch discrimination in children

Another point is that the child might memorize a note, other than the note of interest and after several assessments can give spurious but correct answers, irrespective of the required criterion in the assessment. Hence, after every two cases of principal assessment, we perform the training instruction at a higher range to prevent the intervention of auditory memory in the assessment process. To adapt efficient assessment criteria, we pose the pair notes as the standard. When proffered, the child must select and represent one pair as the note with a higher note. Provided that the child does not give any response following the output representation, that pair must be excluded from the calculation process. Ergo, in each assessment of the sets, 10 responses represented by the child must serve as the criteria.

It must be noted that in the assessment process for each pair, there is a 50 percent chance of giving the correct answers, that is if the child randomly and without adequate active processing presents a selective response to the question regarding the pair of notes, there is 50 percent probability that the answer is correct. Ideally, the child must identify all the pairs correctly to have this task fulfilled. However, as unwanted mistake is probable, a few cases must be considered for such events. Regarding the binomial distribution and recurrent experiments, provided that the number of two incorrect and eight correct answers exist, based on the combination binomial distribution, there will be less than five percent of the error term. To verify the assessment validity, we consider retrieving the success criteria in one more 10-pairs set. Nonetheless, we account for another probable 10-pair choice for the unwanted error. Therefore, to succeed in discriminating each presented pair, the child must give a correct answer to two of the three 10-pair sets at a minimum of 80 percent of the time. The binaural assessments with the same instructions are conducted for all four notes of F#3, E4, G4, and C4.

Data Analysis

According to the guideline, the discrimination threshold for each note is the smallest semitone interval in which a child can respond correctly to 80 percent of two of the three sets of 10-pairs. The numerical findings contained the average pitch discrimination thresholds that were compared using the test related-samples Friedman's two-way analysis of variance by rank; to compare the relationship between findings and children's ages Spearman correlation coefficient was applied. The calculations were carried out using SPSS 22.

Results

Pitch discrimination of 75 children between the ages of 8-12 with an average age of 10.59±1.42 including 38 boys and 36 girls, with average ages of 10.84±1.39, 10.32±1.42, respectively, was assessed; the results did not reveal statistically significant differences (P=0.844).

The frequency distribution of the children based on age is presented in table 1:

Age (Year)	Number	Percent
8	14	18.7
9	11	14.7
10	14	18.7
11	20	26.7
12	16	21.3
Total	75	100

Table 1: Frequency distribution of the ages of children in the study

You can see the general statistics of pitch discrimination in table 2:

Note	Pitch Threshold	Standard Deviation
F#3	5.35	2.26
C4	4.26	2.01
E4	4.21	2.20
G4	4.33	2.18

Table 2: Pitch discrimination statistics on the basis of semitones in various notes

Since the data lacked normal distribution, non-parametric tests were used to make a comparison between the discrimination thresholds of various notes. According to the test related-samples Friedman's two-way analysis of variance by rank, discriminations between the notes were associated with significant differences.

The results demonstrated that the differentiation between the lower notes yielded smaller quantities. This means that the higher the fundamental frequency of a note, the better the note discrimination (Table 3).

Paired Note	P-Value*
E4-G4	1.000

E4-C4	0.013
E4-F#3	<0.001
G4-C4	0.137
G4-F#3	<0.001
C4-F#3	0.029

*Based on Friedman Test

Table 3: Comparison between the discrimination capacities of various notes.

Nonetheless, Judging by Spearman test results, the data did not reveal any correlation between children's age and pitch discrimination within the range of 8 to 12 years of age, for either of the three notes G4, E4, or C4. But there was a significant correlation between pitch discrimination of lowest note, i.e. F#3, and children's age (Table 4).

Note	Correlation Coefficient	P- Value*
F#3	-0.232	0.045
C4	-0.126	0.280
E4	-0.024	0.836
G4	-0.030	0.798

Based on Spearman Test*

Table 4: The correlation coefficient between the age and the pitch discrimination frequency of the study notes

Discussion

Pitch Discrimination and Fundamental Frequency

As is exhibited in table 2, lower notes have a weaker level of discrimination, compared to higher notes. The lower the fundamental frequency of the note under assessment reaches, ipso facto, the more it restricts the child's capacity for pitch discrimination. Randall S. Moore arrived at the same conclusion in his studies of pitch-matching skills in children between eight to eleven years of age. His studies revealed that in these children lower pitch matching is more difficult than higher pitch matching[24]. In the preliminary studies carried out on pitch discrimination and its correlation with the sound's intensity and frequency, J. Donald Harris in 1952 set out to assess the pitch discrimination frequencies in the various levels of intensities, ranging from 5-phons to 30-phons for different frequencies, ranging from 60 CPS to 4000 CPS[25]. He used a method similar to the methods represented in the present study; in his study, two consecutive sounds were sent to the subject and he or she had to decide whether the second sound was treble or bass. The primary results of the study exhibited a significant improvement in the pitch discrimination frequency in response to the increased sound intensity, to the extent that this improvement had a similar pattern in all frequencies. Later on, the proportion of pitch Discrimination Frequency to the Fundamental frequency (DF/F) significantly improved and this trend continued up to the frequency of 2000 Hz. The pitch discrimination frequency, however, displayed a significant decline at the highest frequency 4000 Hz, and was reduced to below the level of study, 500 Hz[25]. Jan O. Nordmark in 1968 take a similar course of action, with the difference that, he expanded the limit of the assessment frequency as high as 12000 Hz, and other than the pitch discrimination assessment of sinusoidal tones, applied an amplitude modulation and studied the pitch discrimination of the modulated tone[26]. The study results were astonishing. There was here, too, a locus of maximum stimulation of 2000 Hz for the pure-tone pitch discrimination; however, this locus was 500 Hz for the modulated sound. He attributed the function dissimilarities to several mechanisms involved in pitch processing and categorized the functional areas of these mechanisms separately for the very-low-, low-, low- and medium-, and high-frequency ranges[26].

Pitch Discrimination and Age

It's observable that there are signs of the age effect on pitch discrimination, solely in the notes with the lowest fundamental frequency (F#3) (P=0.045). Fundamentally, providing the code for pitch discrimination is attributed to the two processes of phase locking and place coding[27]. Place coding is predicated on the process of tonotopic excitation, through which codes for the pitch are carried along the spatial variables of the nerve fibers; the prevailing opinion is that the coding of high-frequencies is mostly carried out through this physiologic mechanism. On the other hand, phase locking possesses the dominant role in the transmission of the pitches with low-frequency signals; this temporal code mechanism has a temporal fine structure and carries locked signals and information related to intonation while maintaining the auditory nerve discharge rate in the same signal frequency[27]. Therefore, in the low-frequency range, the auditory capacities are correlated with the temporal fine structure, which plays a critical role in speech perception in the background noise[28]. Nonetheless, phase locking is correlated with the low-frequency note perception, and continues to specifically develop and mature up to adulthood. Shahin et al. have shown that there is a developmental pathway for musical sound phase locking observed in the brain waves[29]. Depending on the phase locking to detect low notes, discovering signs of phase locking developments, even up to the third decade of life, and having the low-frequency pitch discrimination depending on the phase locking, could serve as evidence to support our findings regarding the effect of age-related development on improving the pitch discrimination in the lowest note (F#3).

Mechanisms underlying Pitch Discrimination

Various studies have suggested different mechanisms for pitch discrimination in low and high frequencies; the mechanism pathway is affected by the stimulus type. There are two mechanisms classified as the "rate mechanism" and the "place mechanism"[30]. The rating mechanism is applied to the low-frequency sounds; the place mechanism is dominant in the coding for high-frequency sounds. However, there is no unanimity regarding the boundary existing between the two mechanisms. The pure tone of the place is represented roughly around 5000 Hz; basically, in the place locking the phase of sinusoidal stimuli is attenuated and as a result, the pitch perception is affected by the phenomenon as well[30]. Nevertheless, for the sounds with modulated frequencies (FM) of 10 Hz or over, place coding is suggested. Moore's paradigm suggests both the mechanism for the pitch perception of the complex tone, are involved in multi-level processing[30]. Taking the results mentioned into account, we could as well postulate a changing place for the coding mechanism for the pitch during the presenting various notes to the central and peripheral auditory system. Through acquiring the natural data of the pitch discrimination, such a probable place of the process transmission is observed in the areas related to note C4. According to the research-based theories, by increasing the fundamental frequency, the mechanism structure involved in the pitch discrimination undertakes the pathway for transformation and within the range of a specific frequency, primarily finds an intermediate condition[30]. In the present study, we could observe the effect of such a condition in note C4. There is an association and correlation observed between the child's age and the pitch discrimination index; nonetheless, after noting C4 and higher areas, this association is removed. Albeit having a significant discrimination difference between the discrimination threshold F#3 and other notes (Fig. 3), this difference sparsely exists in note C4, but there is no statistical difference observed between the discrimination of the two notes.

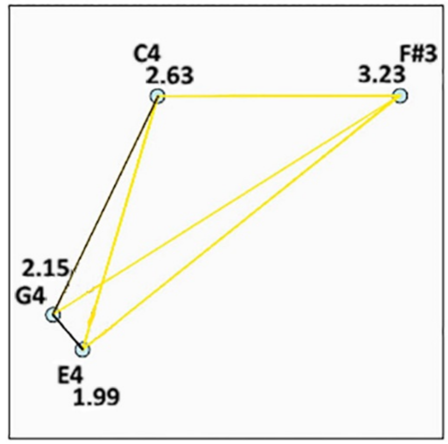

Figure 3: The diagram of related samples Friedman's two-way analysis of variance by rank. The distinct difference is observable between the threshold and the other three notes in the lowest note (F#3, mean rank=3.23), however, arriving at the next note (C4, mean rank=2.63) we can see the significant difference solely remains between the threshold and the two other notes while the two other high-frequency notes still are remaining, no significant difference is observable between them.

Pitch Discrimination and Sex

We studied pitch discrimination thresholds between boys and girls, and the results did not show any sign of the difference between the two genders. This is exactly in consonance with the findings of Randall S. Moore; he, too, did not observe any significant difference between the pitch-matching skills of the boy and the girls within the age range of 8 to 11 years. It is conceivable thus to assume that the pitch discrimination structure between the two genders is identical; at least at the age range of the study, no functional or developmental no difference was observed[24].

Summary

The structure of pitch discrimination for low-frequency sounds is distinguished from high-frequency, and this is observable in the growth process of pitch discrimination in children. For high-frequency sounds, the mechanism of pitch discrimination is built on a structure based on the excitation place, which matures in early childhood. Also, in low-frequency, the mechanism involved in pitch discrimination is built on a structure based on the rate of excitation. The latter is thought to continue its developmental path up to the age range of 8 to 12 years.

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Conflicts of interest

None

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Ethical Statement

None

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