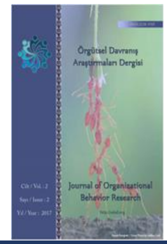
2528-9705

*Örgütsel Davranış Araştırmaları Dergisi*

Journal Of Organizational Behavior Research

Cilt / Vol.: 8, Sayı / Is.: S, Yıl/Year: 2023, Kod/ID: 23S0-1012



# INVESTIGATING THE RELATIONSHIP BETWEEN PITCH DISCRIMINATION AND CONSONANT-VOWEL DISCRIMINATION IN THE PRESENCE OF NOISE IN PERSIAN-SPEAKING CHILDREN AGED 8 TO 12

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*ABSTRACT*

*Selecting target sounds in noisy environments is difficult for any listener, and this difficulty also includes pitch discrimination. On the other hand, one of the abilities of individuals with high pitch discrimination skills, such as musicians, is their high ability to understand speech in the presence of background noise. Can a relationship be found between pitch discrimination in children and their ability to perceive speech stimuli in the presence of noise?*
*A total of 75 children between the ages of 8 and 12, comprising of 38 boys and 37 girls, with no underlying illnesses or disorders and normal hearing, were assessed for their ability to perceive pitch differences and Consonant-Vowel discrimination while exposed to noise. The study investigated the statistical correlation between the computational measures obtained from these assessments. At high levels of signal-to-noise ratio, no statistically significant relationship was observed between the percentage of Consonant-Vowel discrimination in the presence of noise and the power of children's pitch discrimination. However, at lower signal-to-noise ratios, significant statistical correlation between these two quantities can be observed. On the other hand, the differences in these relationships at different levels suggest the possibility of differences in the auditory processing system for pitch discrimination. The ability of pitch discrimination in children is effective in their Consonant-Vowel discrimination in the presence of noise. This phenomenon varies at different levels of signal-to-noise ratio and has the greatest effect at lower levels.*

***Keywords:*** *Pitch Discrimination, Consonant, Vowel, Noise*

## INTRODUCTION

In real-world environments, noise in a complex way reduces speech perception, which clearly affects the performance of automatic speech recognition systems. Difficulty in distinguishing auditory patterns from background noise is a contributing factor to the weakness of speech perception, particularly in settings with multiple sources of sound. The capability to identify important sounds or target auditory signals is compromised in noisy environments. The ability to separate a specific target such as a speaker's voice from a set of confounding signals, the formation of an auditory object, or the separation of an auditory stream is called "auditory streaming"[1].

Typically, sounds come to our ears from various directions in the surrounding space and get mixed and combined before reaching the auditory cochlea. To analyze the auditory scene, it's crucial to perform a preliminary analysis on the auditory inputs by segregating and distinguishing them into auditory objects. This is done by first separating the physical characteristics of the sounds, also called "auditory cues," from their acoustic background and then integrating them into a perceptual stream. The Integration Process, which involves the ability to combine information from different sensory sources into a cohesive concept over time, is a critical aspect of auditory scene analysis that helps us perceive speech[2].

Auditory cues, such as the pitch of the speaker's voice or the position of the sound source, are useful in distinguishing sounds from various sources, enabling auditory streaming and providing suitable input for cognitive resources[3]. The decrease in spectral analysis results in a decreased representation of speech information, particularly consonant-vowel (CV) sounds, and amplifies the impact of noise that has a frequency content similar to speech[4].

Pitch is the perception of frequency and is defined as an auditory perceptual symbol that can categorize sounds on a low-to-high scale[5]. Pitch intervals, which define the change in pitch, are also important for conveying information in specific contexts and contents. In non-tonal languages, pitch may be used to emphasize specific emotions[6], while in tonal languages, differences between two tones with identical pitch patterns can create distinctions[7]. Speech, which is the primary mode of communication, frequently takes place amid the presence of background noise and multiple speakers[8]. Children spend longer periods of time in environments with higher levels of noise compared to adults[9]. In such environments, target speech signals are placed in a background of competitive sounds that can have spectral and temporal masking effects on them[10].

The analysis of pitch is essential in differentiating speech, but it becomes a challenge to estimate them accurately in noisy conditions, particularly when the signal-to-noise ratio is low. While pitch information can enhance the performance of speech recognition systems, estimating them is only feasible if speech is separated from background noise[11]. The process of distinguishing speech and non-speech signals is complex and involves an extensive neural network comprising both subcortical and cortical areas of the brain[12]. Background noise can mask low-intensity speech components and diminish the signal-to-noise ratio, making it difficult to access intrinsic speech cues like temporal envelopes, which are critical for comprehending meaningful content[13].

Nevertheless, the tonal and pitch pattern analysis is used as a central auditory system tool to extract the desired sound from background noise[14]. However, can a relationship be assumed between the power of pitch discrimination and speech perception at different levels of background noise?

## 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 37 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[21].

Each stimulus lasts for a total of 500ms ± 50ms. 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[22]. 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.

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[23]. 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. 1). One of the features of pitch assessment is the intervention of memory in the process of note retrieval[24]. 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. 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

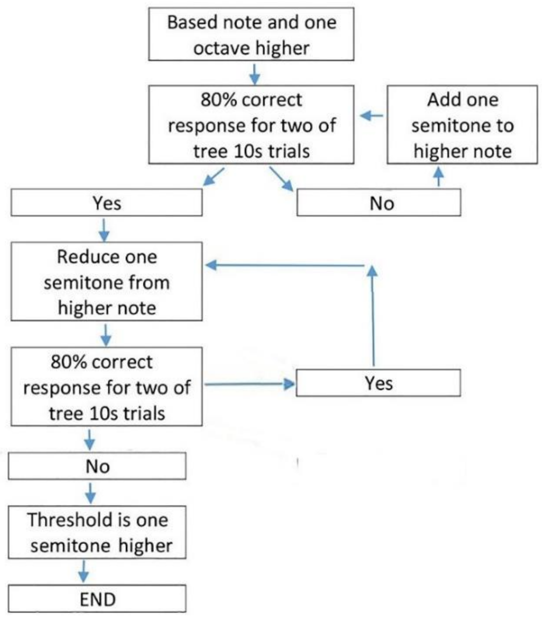


**Figure 1.** the flowchart of the assessment of the natural threshold of pitch discrimination in children

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.

### CV in Noise test

The test of CV in noise is a Non-sense Syllable Test (NST) assessment performed to quantify the audition abilities in noise[25]. In such a test, the syllables used are void of any semantic and syntactic meaning; therefore, to restrain the higher levels of speech perception, to annul the possible effect of linguistic cues, and to provide a ground for more meticulous examination of the process of ascending pathways and lower levels of the brain stem[26].

In this test, non-sense syllables in White Noise are presented in various signal-to-noise ratios (+12, +6, Zero, -6, -12 dB), and the individual must repeat the syllables he or she hears; the scores are calculated as a percentage of Non-sense Syllable recognition[25].

The Persian version of this test was designed and validated in 2016 in Iran[27]; it consists of four lists, each containing 25 Non-sense Syllables imitating the Explosive Consonants /g/, /k/, /d/, /t/, /b/, /p/ and /q/ in combination with long vowels and applied. In the process of norm-referencing via a CV in noise test, the validity and reliability of the lists have been evaluated and authenticated for use in children at age of 8-12[28].

The test at the level of 40 dB HL in binaural mode under headphone was performed; the results in each level were calculated and recorded based on the percentage of frequency of correct consonant-vowel answers out of 25 tests existing in the list.

### 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 and CV in noise discrimination. To compare the relationship between pitch discrimination thresholds and CV in noise discrimination scores, Spearman correlation coefficient was applied. The calculations were carried out using SPSS 22.

## RESULTS AND DISCUSSION

Pitch discrimination were evaluated in 75 children with a mean age of 10.59 ± 1.42 years, including 38 boys with a mean age of 10.84 ± 1.39 years and 37 girls with a mean age of 10.32 ± 1.42 years. There was no significant difference in age between boys and girls (P = 0.110).

**Table 1.** the frequency distribution of the children by age.

| 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** |

Following the assessment of the ability to differentiate between pitch, this capability was calculated for the four notes F#3, C4, E4, and G4 in terms of semitones. You can see the overall statistics of pitch discrimination in Table 2:

**Table 2.** Statistics of pitch discrimination in semitones for different notes

| 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** |

Along with the assessment of pitch discrimination, the CV in Noise discrimination index was also evaluated in the presence of noise for these children and was calculated in different signal-to-noise ratios. It is noteworthy that during these assessments, the relationship between the CV in Noise (CVIN) discrimination index at -12 dB and -6 dB levels and the threshold of discrimination for notes F#3 and C4 was observed. At higher signal-to-noise ratios, no such correlation was detected. However, the correlation was only noticeable for the notes E4 and G4 when the signal-to-noise ratio was -12 dB (Table 3).

**Table 3.** The correlation coefficient was calculated between the pitch discrimination and CVIN discrimination scores while exposed to noise under binaural presentation conditions.

| | CV in Noise Score Correlation Coefficient (P-Value)* | | | | | |
|---|---|---|---|---|---|---|
| Note | Silent | S/N = +12 | S/N = +6 | S/N = 0 | S/N = -6 | **S/N = -12** |
| F#3 | -0.044(0.711) | 0.110(0.350) | 0.176(0.132) | 0.018(0.876) | -0.390(0.001)* | **-0.652(<0.001)*** |
| C4 | -0.021(0.859) | 0.101(0.387) | 0.043(0.715) | -0.055(0.637) | -0.319(0.005)* | **-0.558(<0.001)*** |
| E4 | -0.083(0.481) | 0.111(0.344) | 0.122(0.297) | 0.037(0.755) | -0.188(0.106) | **-0.484(<0.001)*** |
| G4 | -0.009(0.938) | 0.038(0.747) | 0.063(0.591) | 0.028(0.812) | -0.215(0.064) | **-0452(<0.001)*** |

*Based on Spearman correlation coefficient

From Liberman's standpoint, speech is perceived using distinctive processing mechanisms that differentiate it from all other sounds. In fact, he believes that "speech is a unique process."[29].

As mentioned, simultaneous auditory event segregation occurs based on various acoustic features such as spectral, temporal, and spatial cues through "top-down mechanisms." However, it should be noted that stream segregation is a dynamic process in the sense that it is influenced by "bottom-up" cognitive mechanisms and is adjusted based on previous experiences and executive processes. Therefore, by increasing the power of auditory discrimination, such as pitch discrimination, the ability to analyze and segregate speech sounds from background sounds and other speech sounds can be improved.

Some studies have estimated the necessary signal-to-noise ratio for accessing at least 50% word discrimination in typically developing children to be 2.5 dB (SD=0.3)[30]. This means that in our research, we should expect a decrease in CVIN discrimination at signal-to-noise ratios of 0 dB or lower. However, these values were reported for meaningful words and our study includes meaningless CV stimuli, which may affect the indices to some extent. In the results of our study, no significant relationship was found between discrimination scores for CVIN up to a level of 0 dB, which could be due to the any prominent effect of background noise on the results of this test ($P>0.05$). Nonetheless, a significant correlation was observed between the power of discrimination for word recognition and the percentage of CVIN discrimination for both signal-to-noise ratios of -6 dB and -12 dB. The data clearly show that the lower the signal-to-noise ratio, the more significant the effect of noise on CVIN discrimination.

Speech comprehension in the presence of noise is a complex task that requires the separation of the target signal from competitive background noise. This process becomes even more complicated by attenuating the acoustic signal in such a way that the noise disrupts the perception of fast spectral-temporal combinations such as stop consonants[31]. It is widely accepted that the auditory cortex, aided by the efferent system, enhances and clarifies the subcortical sensory manifestations of sounds by amplifying the target signal and inhibiting irrelevant competing background noise[32]. Despite limitations in research and accessible data, studies have shown that music training, even in relation to musical sounds, can improve the activity of the Medial Olivocochlear Bundle (MOC), which is likely due to the enhancement of the lower ascending pathway of the brain cortex[33]. This phenomenon may offer functional benefits such as bolstering the protective function against sound-induced damage, enhancing auditory discrimination in noisy environments, and improving attention and auditory learning[34]. Furthermore, the MOC Bundle can lead to improving complex acoustic patterns such as speech in the presence of noise[35]. Essentially, the effect of the MOC Bundle on speech comprehension in the presence of noise is likely due to its impact on auditory fiber characteristics such as adaptation and dynamic range, which can improve the coding of complex signals such as speech in noisy environments, and by regulating outer hair cell membrane properties, it can improve temporal resolution.

In general, the MOC Bundle system can improve the cochlear function in tracking rapid changes in amplitude, which is observed in speech under noisy conditions[36]. Since a notable part of musical skills is related to the ability to distinguish between different pitches, it is not unexpected that the effects of this prominent ability would also be observed in the results of our evaluations. Better pitch discrimination in children can lead to improved CV discrimination in the presence of noise, which can be partly due to the improved function of the MOC.

Another tangible indicator was observed when comparing the relationship between frequency discrimination at different frequencies with CVIN discrimination. Upon examining the statistical relationship between CVIN discrimination and the level of pitch discrimination for each of the four evaluated notes at the CVIN-12 level, a significant relationship was found ($P<0.001$). However, at the CVIN-6 level, the conditions were slightly different. At this level, the pitch discrimination level of note F#3 ($P<0.001$) and note C4 ($P=0.005$) showed a significant statistical relationship with CVIN discrimination. However, notes E4 ($P=0.106$) and G4 ($P=0.064$) did not show any statistical relationship with CVIN discrimination at this level.

Various studies have proposed different mechanisms for low and high frequency discrimination, and the pathway of this mechanistic change is influenced by the type of stimulus. These two mechanisms are classified as Rate Mechanism and Place Mechanism[37]. The Rate Mechanism is described as the mechanism for encoding low-frequency sounds, while the Place Mechanism is dominant in encoding high-frequency sounds. However, there is no agreement on the boundary between these two mechanisms. The pure-tone threshold for Place is expressed at around 5,000 Hz, which essentially weakens the phase lock of sinusoidal stimuli and also affects frequency discrimination[37].

However, for sounds with a frequency modulation (FM) of 10 Hz and above, a place encoding mechanism is suggested[37]. On the other hand, for periodic tone bursts, the upper limit of the temporal rate mechanism is between 200-300 Hz, while the lower limit of the place mechanism is around 2000 Hz, and the region between these two frequencies indicates a mixed mechanism in coding, with the boundary estimated at 600 Hz[38]. The Moore pattern for understanding complex up-down patterns involves both mechanisms in a multi-level processing scheme[37]. In 2004, Nikolai Novitski et al. estimated the possibility of a change in the neural mechanism of pitch discrimination coding around a frequency of 1000 Hz through a study using pure tones ranging from 250 to 4000 Hz to record mismatch negativity responses[39]. Considering these results, it is essential for us to imagine a spatial change in the structure of pitch coding in presenting different notes on the environmental and central auditory system.

Based on research theories, with an increase in the fundamental frequency, the involved structure in pitch discrimination undergoes a nature-changing path and is eventually placed in intermittent conditions[37-39].Based on this, the different pattern of CVIN discrimination with the pitch discrimination and specifically at a signal-to-noise ratio of -6dB, may be an indication for determining the changing location of the mechanism of pitch discrimination in the auditory environment system for our research sounds. Such relationships suggest that the mechanism underlying pitch discrimination may be more affected by the presence of background noise, and therefore the improvement of CVIN discrimination is evident from the same initial levels of background noise. However, the resistance of the mechanism related to treble sound discrimination against the effect of background noise shows its improvement only at the lowest signal-to-noise levels, and depicts a distinct function of bass sounds. Another rationale is that the ability to distinguish treble sounds might underlie the discrimination of certain parts of speech that are more resilient to noise, and as a result, this ability can have a substantial impact at lower signal-to-noise ratios. On the other hand, the features sensitive to damage caused by noise exposure have a stronger association with the discrimination of bass sounds and, therefore, the relationship between pitch discrimination and CVIN discrimination is also evident at higher levels of signal-to-noise ratio in the regions of bass sounds.

## CONCLUSION

Improvement the pitch discrimination in children with normal hearing results in better consonant-vowel discrimination in the presence of noise, particularly at the lowest signal to noise levels. However, this pattern shows functional differences for treble and bass sounds and demonstrates its differences at different levels of signal-to-noise ratio. The difference in the study's results indicates the possibility of differences in mechanisms and factors involved in pitch discrimination in different frequency regions.

**ACKNOWLEDGMENTS:** I would like to express my gratitude to Mr. Saeed Tavangar, who made the necessary arrangements with relevant bodies to pave the way for implementation of this project.

**CONFLICT OF INTEREST:** None

**FINANCIAL SUPPORT:** None

**ETHICS STATEMENT:** None

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