PITCH PERCEPTION IN CHILDREN -A SYSTEMATIC REVIEW

NIKHILESH H C

20AUD021

II M.Sc. (Audiology)

This Dissertation is submitted as a part of fulfilment

for the Degree of Master of Science in Audiology

University of Mysore

Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING

Manasagangothri, Mysuru 570006

August, 2022

CERTIFICATE

This is to certify that this dissertation entitled "**Pitch Perception in Children: A Systematic Review**" is a bonafide work submitted as a part of the fulfilment for the degree of Master of Science (Audiology) of the student with Registration Number: 20AUD021 This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

August, 2022

Dr. M. Pushpavathi

Director

All India Institute of Speech and Hearing

Manasagangothri, Mysuru-570006

CERTIFICATE

This is to certify that this dissertation entitled "**Pitch Perception in Children: A Systematic Review"** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

August 2022

Guide

Dr. Devi. N

Associate professor in Audiology

All India Institute of Speech and Hearing

Manasagangothri, Mysuru-570006

DECLARATION

This is to certify that this dissertation entitled "**Pitch Perception in Children: A Systematic Review.**" is the result of my own study under the guidance of Dr. Devi N Associate professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration No: 20AUD021**

August, 2022

ACKNOWLEDGEMENT

Words cannot express my gratitude to my guide, ***Dr Devi. N****, for her patience and guidance throughout my dissertation. Thank you so much ma'am.*

I would like to express my deepest gratitude to ***Dr M. Pushpavathi****, Director of the All India Institute of Speech and Hearing, Mysuru.*

I would like to extend my sincere thanks to ***Prakruthi Ma'am*** *and* ***Rashmi Ma'am*** *for their advice and suggestions.*

Special thanks firstly to ***Delvin*** *for being an incomparable study buddy throughout my AIISH journey, I greatly appreciate your generosity of time and effort. Secondly, to* ***Nethra,*** *for your unparalleled help and support in my dissertation, thanks for being a great friend.*

Thank you, ***Prakruthi V.J****, one of my go to people. Thanks for being a true friend, even when times were at their most cloudy and gray. Words cannot express how grateful I am to you.*

Thanks, ***Mesmin, Sanjay*** *and* ***Akash*** *for all the fun times we had.*

Memories with the right people are always priceless. Thank you 5sm. You guys are truly dependable and reliable and are always selflessly there for me. I can't explain it but I sincerely thank you guys.

I am grateful to my parents. You've sacrified so much to support me through the good and bad times. Thank you.

*I'd like to acknowledge my dissertation partners -****Monisha akka*** *(unofficial co-guide) and* ***Chinnarasu****. Thank you, guys.*

Memories bring memories bring back you... I would be remiss in not mentioning all my teachers, staffs, batchmates- Class Artifacts and Master Artifacts, and for all the posting people and the trvaelling buddies for all the wonderlust moments.

Arigato anime!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Pitch is a psychoacoustic correlate of frequency perceived as high and low by an individual. It plays a vital role in the perception of speech and non-speech sounds (music and other emotions). It also helps in describing prosody and tonal dialects in languages such as Mandarin and Cantonese and aids in defining the word meaning. Pitch differences can aid listeners in separating and making sense of conflicting sound sources in challenging acoustic situations. The purpose of the current review was to summarize existing literature on various tests and stimuli used to assess the pitch perception ability in children with normal hearing and hearing impairment. The search for the articles began with finalizing appropriate keywords, putting those through various search engines from 2012 to 2022. The retrieved articles were assessed in two stages: title and abstract screening, followed by a full-length article review. Seven studies were finalized at the end of the search process. The review showed up-down/rising–lowering procedure, tonal contrasts, just noticeable difference (JND), pitch sweeps, lexical tone perception, direction and perception of pitch glides, and focus sentences. The tests were assessed using either one interval two alternative forced choice method (1I-2AFC) and three interval three alternative forced choice method (3I3AFC). It was noticed that when the pitch cues were unattainable for children with cochlear implants (CI), durational and amplitude cues helped to determine the stress and intonation perception. In children, F_0 *onset served as a cue for identifying similar contour tones. Children around eleven years show improvement in the direction of pitch discrimination as the sensitivity increases with age*

Chapter 1

INTRODUCTION

Every day we are exposed to different types of sounds in the environment. Sound is the speed of variations ranging from compressions to rarefactions to compressions. Any hearing organism can only physically receive a certain frequency range of sound. The typical range of sound frequencies humans hear is between 20 Hz and 20,000 Hz (20 kHz) (Olson & Harry, 1967). Sound waves are analyzed in these six ways like pitch, duration, loudness, timbre, sonic texture, and spatial location. Pitch is a psychoacoustic measure of frequency (Bruton, 2015). Our perception of the pitch of distinct sounds varies depending on their different frequencies. High-frequency vibrations are higher pitched than low-frequency sounds, and vice versa. The unique role of the auditory system differentiates among various pitches. Pitch is therefore determined in part by the area of the cochlea firing the most frequently (Walinga & Stangor, 2014).

One of the primary auditory sensations, pitch, serves as a cue for sound segregation and is crucial for the perception of melody, harmony, and prosody in music and speech. Pitch is the aspect of an auditory perception whose variation is linked to musical melodies, or more generally, the pitch is the perceptual correlate of a sound waveform's repetition rate. Pitch thus primarily depends on the fundamental frequency (F_0) of a complex tone and the frequency of a pure tone (Plack & Oxenham, 2005). Most pitch-invoking sounds in the environment are complex tones and harmonic components with integer multiples of the F_0 frequency. A complex tone's F_0, the fundamental frequency (first harmonic), and the waveform's overall repetition rate typically serve as pitch. Nonetheless, it has long been understood that although the fundamental component is deleted or rendered inaudible by masking noise, the pitch remains intact (Walker et al., 2011).

1.1 Perception of Pitch for Pure Tones

Low frequencies produce low-pitch sensations, while high frequencies produce high-pitch sensations, which means that the frequency of a pure tone primarily determines its pitch. Changes can influence pitch in tone intensity, but this effect is typically weak and erratic. It is still unclear exactly what data the brain uses to represent pitch, despite the seemingly straightforward mapping from frequency to pitch. The most frequently mentioned possibilities are "place" and "temporal" codes. Depending on the tone's frequency, the basilar membrane (BM) in the cochlea responds differently to the tone, with high frequencies producing the most activity close to the base and low frequencies producing the most activity close to the apex. Since each auditory nerve fibers neural activity corresponds to mechanical activity along the basilar membrane at a specific location, changes in the BM vibration pattern are reflected by changes in which auditory nerve fibers respond more strongly. Tonotopic representation is the term for this frequency mapping to location or frequency to fiber (McDermott & Oxenham, 2008).

As per the temporal theory, the auditory nerve's action potentials, or spikes, are the time to indicate pitch. Spikes seem more likely to happen around one phase in the cycle of a sinusoid at low frequencies. The time gap amongst sets of successive spikes is anticipated to be a multiple of the sinusoid's period because of this feature, known as phase locking (Plomp, 1967; Ritsma, 1967; Rose et al., 1967).

1.2 Perception of Pitch of Harmonic Complex Tones

Many researchers (Bernstein & Oxenham, 2003; Dai, 2000; Moore et al., 1985; Plomp, 1994; Ritsma, 1967; Shackleton & Carlyon, 1994) have revealed that low-numbered harmonics generate a more prominent and accurate pitch than high-numbered harmonics, indicating that the location or time information provided by resolved harmonics is more significant than the temporal envelope information offered by unresolved harmonics (Houtsma & Smurzynski, 1990). When the phase relationships are modified, the envelope becomes considerably less modulated, typically resulting in worse pitch perception and discrimination, but only when unresolved harmonics are present in the stimulus (Bernstein & Oxenham, 2006). The temporal envelope of unresolved harmonics conveys some pitch information (Kaernbach & Bering, 2001), as well as temporal-envelope changes in random noise (Burns & Viemeister, 1981), suggesting that at least some components of pitch are generated from timing information rather than place information in the auditory nerve. Auditory frequency selectivity and harmonic resolvability can predict pitch discrimination accuracy, implying that peripheral filtering is essential for comprehending pitch coding (Bernstein & Oxenham, 2006). Artificially enhancing harmonic resolvability by providing alternate harmonics to opposite ears does not improve pitch perception (Bernstein & Oxenham, 2003).

1.3 Perception of Pitch for Multiple Sounds

The scant research also suggests that resolved harmonics may play a significant role in the future. The listeners were presented with two complicated tones played simultaneously, each with only two neighboring harmonics—four components.

The result suggests that listeners could distinguish the pitches of both complexes if at least one of the four components could be resolved (Beerends & Houtsma, 1989).

When two complexes with multiple harmonics were presented at the same volume overall and in the same spectral region, only one of the complexes' pitch could be discerned; when the stimuli were filtered to remove all resolved harmonics, The combination sounded more like a crackle than two pitches, implying that listeners are unable to distinguish between two periodicities inside a single temporal period (Cariani & Delgutte, 1996).

1.4 Pitch Coding and Pitch Processing in the Brainstem

The cochlear nucleus (CN), the superior olivary complex (SOC), the nuclei of the lateral lemniscus (LL), and the inferior colliculus (IC) process the information in the auditory nerve (IC). If temporal coding is used for pitch, this information is likely extracted somewhere in this part of the auditory pathway, given that the upper-frequency limit of phase locking continues to drop as the auditory pathway continues.

Important details about how and where the pitch is coded and processed in the human brain have been found in neuroimaging studies. The output of a pitch extraction technique does not appear to be represented by the frequency-following response (FFR). This raises concerns about the method used to create a cohesive experience from the peripheral neural signal. Since a wide range of spectral and binaural stimuli can yield the same pitch, it has been hypothesized that the representations converge at some point along the ascending auditory pathway. The findings imply that a code based on the neural firing rate of the brain replaces the initial temporal pitch code in the auditory peripheral. The information from the various harmonics of complex tones is integrated into the upper brainstem or auditory cortex to create a general representation of pitch (Plack et al., 2014).

1.5 Pitch in Auditory Perception

Auditory perception is the capacity to recognize and comprehend a phonemic, linguistic, grammatical, or syntactic signal. Each music's temporal facets contribute significantly to the development of auditory perception. The listener can tell whether the speaker is making a statement or a question by the tone of voice, which is a key conversational marker. When making a statement, the speaker's pitch will generally remain fairly constant; however, when asking a question, the speaker's pitch will rise toward the end. The tone of a speaker's voice can also give away how they are feeling. An enthusiastic speaker will probably use a higher, more varied pitch, whereas an apathetic speaker will probably choose a mid- or low-pitched monotone (Lambert, 2017). In normal hearing, the place of the peak response on the basilar membrane provides a spatial clue to pitch, and neural phase locking provides a temporal cue to pitch, i.e., neurons prefer to fire in phase with the basilar membrane vibration. Normal hearing place cues to pitch are imprecise: The peak of basilar membrane (BM) excitation changes basally as the amplitude of a pure tone grow, and the neuronal firing rate saturates across an area around the peak yet the perceived pitch remains rather steady (Moore, 2012). Another example of the relevance of temporal cues is that tones with just unresolved harmonics create pitch perceptions but are not as strong as those with resolved harmonics (Houtsma & Smurzynski, 1990).

Even if no energy is present at F_0, the perceived pitch of a harmonic tone is similar to the fundamental frequency, independent of the harmonic amplitudes. The resolved harmonics are the lowest harmonics that create recognizable peaks in the basilar membrane response. Each resolved harmonic provides a distinct time and place cue. Because the cochlea is activated in a substantial section, the remaining (i.e., unresolved) harmonics do not provide a distinct location cue. Still, they provide a temporal cue because the basilar membrane response modulates amplitude at F_0 (Plack & Oxenham, 2005).

1.6 Importance of Pitch Perception

The physical characteristics of sound, such as frequency or repetition rate, are most closely related to the perceptual quality of the pitch. It is crucial for auditory perception in speech because it controls and transmits information about prosody and the speaker's identity. Furthermore, the cocktail party issue can be solved by distinguishing between conflicting sources due to differences in pitch between sounds (Oxenham, 2018). According to American National Standards Institute (ANSI),1978, the definition of pitch is "that subject dimension of sound that orders sound from low to high" (Yost, 2009). Pitch has proven to be a crucial component for both music and speech perception (McDermott & Oxenham, 2008).

Two peripheral auditory systems, place coding and phase locking, are known to encode pitch. Based on tonotopic excitation and involving pitch cues transmitted through spatial alteration of nerve fibers, this physiological mechanism is thought to dominate high frequency (HF) coding. However, phase locking is a time-based technique that locks onto the Temporal Fine Structure (TFS) of the signal for low-frequency (LF) transmissions. It is more efficient to communicate intonation by maintaining the firing rate of the auditory nerve fibers at the same frequency as the signal (Vaerenberg et al., 2011).

Tone height and tone chroma together comprise the pitch's two-dimensional percept. Tone height is the portion of pitch that keeps getting higher as frequency rises. Two tones separated by an octave sound similar even though they vary in tone height. This is known as tone chroma (Bachem, 1950). Pitch contours express emotional information in speech and music, and pitch signifies object identity information such as body size, age, and gender (He & Trainor, 2009). Pitch analysis is extremely useful for perceptually distinguishing and recognizing various sound sources. The f_0 of a complex sound correlates to its perceived pitch (Shofner, 2005).

Infants may extract information about the missing fundamental pitch and categorize sounds based on that pitch without other acoustic cues (Clarkson & Clifton, 1985). From a young age, infants appear sensitive to pitch in speech and music. Infants as young as three months old have shown the capacity to discern pitch contours in syllables and sentences (Nazzi et al., 1998).

1.7 Perception of Pitch in Children

Development for the perception of music acquires with the acquisition of cognitive, motor, emotional, and perceptual skills during the pre-natal period '(Hepper, 1992). The spectrum of acoustic information available to the fetus is broadened as the cochlea develops, enabling better discrimination of acoustic patterns crucial for pitch perception. In the early stage of infancy, low-frequency sounds will be developed first, followed by higher frequency as the child develops (Hepper & Shahidullah, 1994). New-borns' perceptual skills demonstrate that they can process and differentiate various simple and complex auditory sounds (Eimas et al., 1971; Kuhl et al., 1992). The development of music perception in the child varies from individual to individual based on the child's innate ability and environmental stimulation (Lamont, 1998). According to Trehab et al. (1986), four to six years of children perceive the change in semi-tones better than infants. According to research, by age 6 or 7, children may be able to identify pitches similar to adults (Trainor & Trehub, 1994; Trehub et al., 1986). 5- and 9-year-old musically trained children perceived pitch better than untrained individuals of the same age group (Morrongiello & Roes, 1990). Children between the ages of 6 and 16 can recognize pitch in music, which improves as the child matures (Lamont, 1998).

1.8 Perception of the Pitch by Individuals with Hearing Impairment

Individuals with hearing impairment frequently perceive the pitch of both pure and complex tones worse than normal hearing individuals. Still, listeners have significant individual variation, as many auditory skills exist (Moore & Carlyon, 2005). Moore and Peters (1992) studied pitch discrimination in younger and older normal-hearing and hearing-impaired individuals using pure tones and complex tones filtered to have the first 12 harmonics, only harmonics 1-5, or harmonics 4-12 or 6-12. The results reported a wide range of performance among hearing-impaired individuals; some individuals had near-normal ability to distinguish minor variations in pure tone frequency, while others had severely limited ability to do so. Poorer frequency selectivity in wider auditory filters is frequently associated with hearing. Poorer frequency selectivity should result in worse pitch perception and greater frequency difference limens (FDLs), according to the place theory of pitch. Only a small correlation existed between FDLs and auditory filter bandwidths (Glasberg & Moore, 1990; Patterson, 1976), suggesting perhaps that place coding cannot fully account for pure-tone pitch perception. In patients with auditory neuropathy, low-frequency pure-tone frequency discrimination and modulation perception are often severely impaired

(Zeng et al., 2005). Moore and Peters (1992) found variable results regarding complex tones, with one interesting exception: No listeners with auditory filters that were broader than usual displayed normal F0 discriminating of complex tones. They focused on the rapid change in normal-hearing listeners' pitch perception from good to poor as the lower harmonics are gradually removed from a complex harmonic tone (Houtsma & Smurzynski, 1990). Accurate pitch perception relies on resolved harmonics. As the lowest harmonics in each stimulus are gradually eliminated, pitch perception should deteriorate more quickly in those with broader auditory filters. Listeners with hearing impairment should reach the point when no resolved harmonics remain in the stimulus sooner than listeners with normal hearing, which should be reflected in the pitch perception generated by the stimuli. Bernstein and Oxenham (2008) found a significant correlation between the lowest harmonic number present at the point where the F_0 difference limens (F_0DLs) became markedly poorer and the bandwidth of the auditory filters in individual hearing-impaired subjects. The findings support that peripheral frequency selectivity influences how complex tones are perceived in pitch and that listeners with hearing impairement with worse peripheral frequency selectivity have worse complex pitch perception.

1.9 Perception of the Pitch in Individuals with a Cochlear Implant

Cochlear implants (CIs) users claim that both place and time cues can be used in specific situations. Townshend et al. (1987) assessed the participants to rate the pitch perception associated with each electrode and have often discovered that stimulating electrodes close to the base of the cochlea results in higher pitch perceptions than stimulating electrodes close to the apex. Individuals with a unilateral CI but some residual hearing in the opposite ear have shown that pitch generally rises with stimulation of more basally placed electrodes, in accordance with expectations based on the tonotopic representation of the cochlea (Boëx et al., 2006).

The general conclusion has been that CI/s do not produce the same fine-grained pitch perception as normal-hearing participants do when place and rate coding is used. Since most existing implants only transmit temporal envelope information and ignore the temporal fine structure, this might partly be caused by the complete lack of resolved harmonics in cochlear implants. Cochlear implant users can get pitch information from temporal-envelope (and pulse-rate) cues, but pitch perception generally seems weak (McDermott & Oxenham, 2008). Most CI users cannot distinguish changes in stimulation rate above 200–300 Hz. There is evidence that electrode (place) and rate (timing) cues produce separable perceptual dimensions in studies that have independently varied both, indicating that location and timing cues do not correspond to the same pitch dimension (Todd et al., 2017).

Need for the Study

Pitch has proven to be an important factor in music and speech perception (Moore, 2008). Both simultaneous and sequential sounds appear perceptually organized, significantly influenced by pitch. Even though the pitch is essential for music perception and might contribute to the perceptual separation of competing sounds, such as two people speaking at once, our ability to distinguish between different pitches is poorly understood. Dynamic pitch sensitivity may serve as a more accurate and detailed estimation of a listener's capacity to interpret voice pitch information in everyday situations. Harmonic pitch sensitivity is essential not only for the perception of music (McDermott & Oxenham, 2008) but also plays a role in speech comprehension in terms of speech intonation (Cutler et al., 1997), lexical tone recognition (Kuo et al., 2008), vocal emotion (Murray & Arnott, 1993), or assisting in separating the speech of a target speaker from a competing noise (Brokx & Nooteboom, 1982). Little research has been done to determine how context affects the weighting of auditory cues to perceive lexical tones, particularly in children. Several tests have lately been designed to measure pitch perceptual skills. As a result, an assessment of existing tests of pitch perception in children is required (Edwards et al., 2014). Due to perceptual limitations associated with hearing impairment, children are expected to perform worse than normal hearing children (Moore,1996). Wang et al. (2013) found that patients with cochlear implants (CIs) CI performed significantly worse than adult listeners with normal hearing (NH) and adults with severe hearing loss in terms of tone perception. Many children with severe-profound hearing impairment receive CI early. Children who received CI early on may be better able to perceive information relevant to F_0 because of the increased neural plasticity throughout the critical period. The ability of paediatric CI users to perceive pitch has not been well studied. However, data shows that bimodally fitted children are more effective at intonation perception than those who use CI alone (Straatman et al., 2010). So, there is a need to study pitch perception in early implanted children to measure the cochlear implant outcome.

There is a necessity for a systematic review of the available tests of pitch perception for individuals with hearing impairment and normal hearing sensitivity. Most research on pitch perception has been conducted on adults and continues to be investigated in adults. Therefore, it would be interesting to see if children can resolve partials the same way adults can (Deroche et al., 2012). So this helps in comparing the pitch perceptual test results of the individuals with hearing impairment, those who are using hearing aids or cochlear implants, and normal hearing individuals, which helps audiologists assess and manage individuals with hearing impairment.

Aim of the study

The current study looks into relevant studies on various tests used to assess pitch perception in children with normal hearing and hearing loss. The present study aims to review the significant studies conducted in the past ten years (2011-2021).

Research Question

- What are the several tests designed to examine pitch perception of children with normal hearing and hearing impairment?
- How are these tests for pitch perception efficiently assessing the pitch perception of children with normal hearing and hearing impairment?

Chapter 2

METHODS

The systematic review was conducted based on the (PRISMA) Preferred Reporting Systematic Review and Meta-Analysis Statement. A systematic literature search was carried out for peer-reviewed articles published from 2012-2022.

2.1 Information Source

The databases for the following were extensively searched for studies on Pitch perception in children: Pub Med, Google Scholar, and Science Direct. Lists of references and citations were searched manually for further relevant studies.

2.2 Search Strategy

For studies on pitch perception in children, databases were searched using various methods. Some of these included Google Scholar, PubMed, and Science Direct. The references and citations were manually checked to find more relevant studies. "Pitch perception' or "pitch coding in children" or "pitch contours" or "fundamental frequency" or "hearing loss children" or "pitch encoding" or "hearing impaired Children" or "deaf children" or "hearing loss children" or "tone glides perception" Were used as the key terms for searching studies.

2.3 Study Selection

The specific inclusion and exclusion criteria for the selection of studies were as follows.

2.3.1 Inclusion Criteria

1. Original articles containing human subjects with appropriate samples, practical treatment approaches, and relevant statistics will be considered.
2. Articles focused majorly on the assessment of pitch encoding will be included.
3. The articles focus on children with normal hearing and with hearing impairment
4. An article focuses on pitch coding at the cortical and sub-cortical functioning with behavioral and electrophysiological assessment protocols.
5. The selection was based on PECOS criteria:

   Participant- Children with hearing impairment

   Exposure- Pitch perception tests

   Control- Children with normal hearing - Tests results of pitch perception/detection/discrimination and its correlation with audibility

   Study Design- Experimental Studies

2.3.2 Exclusion Criteria

1. Articles with lower quality methodology and language aside from English will be excluded.
2. Assessment of individuals with other co-morbid conditions will be excluded.
3. Case reports, letters to editors, and editorials will be excluded.

2.4 Data extraction

The results of the review were analyzed using the Rayyan QCRI systems. Then eliminate the duplicates. The studies that met the inclusion criteria were identified by screening the titles and abstracts retrieved from the search strategies. After that, the full text of the potential studies was retrieved and matched to see if they were eligible.

The extracted data included article title, author detail with their affiliation, year of publication, research design, study, population sample size, age group comparison, method of outcome measures, and keyword specific to pitch perception in children.

2.5 Quality assessment

The critical appraisal skill program was used to conduct a methodological quality assessment of the individual studies. The findings have been shown in the result section in detail.

Chapter 3

RESULTS

A total of 8094 articles were identified using database searches and through references and citations, and 2072 duplicates were eliminated. A total of 782 articles were included in the title/abstract screening. Following the titles and abstracts review, 39 articles were selected for the full-length article screening. Seven articles matched the inclusion criteria in the study. The remaining 32 articles were excluded mainly because of the study design (pilot study, systematic review, letter to the editor, case reports) and irrelevant study population (adults, infants, and non-human subjects). A detailed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart for the selection of the study is shown in Figure 3.1

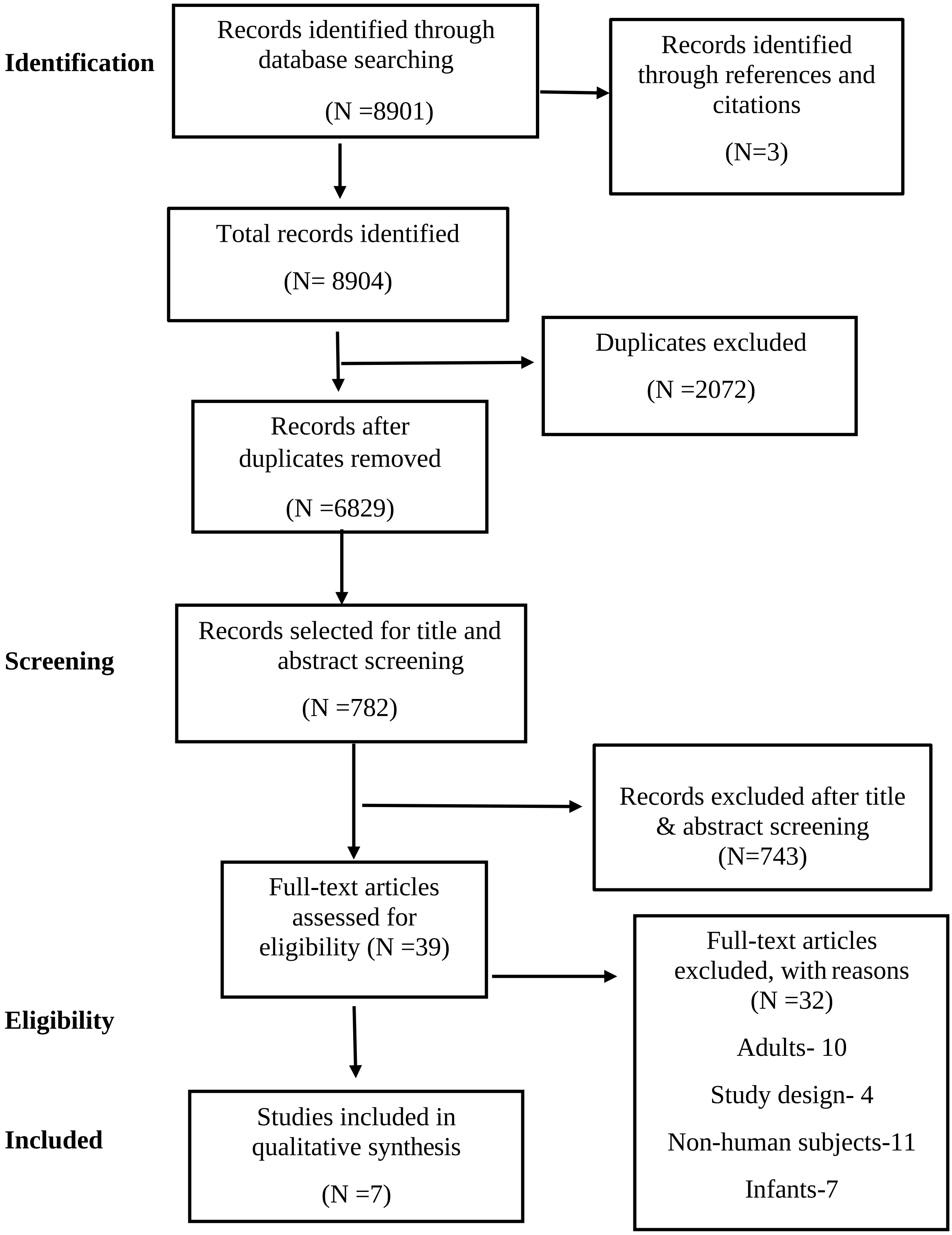

Figure 3.1

PRISMA flowchart for the selection process of articles included in the review.

3.1 Study Characteristics

The study characteristics of all studies were categorized in PECO format. It's given below.

Population: The participants in the study included were all children in the age range from 2 to 12 years. All the participants in the study were without any co-morbid conditions like intellectual disability, autism, dyslexia, and ADHD, etc., and no middle ear-related infections. Participants included were children with hearing impairment as well as normal hearing children.

Exposure: In the current review, various pitch perception-related tests were considered. All the study included has the testing parameter concerning pitch, such as F_0 discrimination, JND, pitch high and low, rising-falling, pitch identifications, etc.

Comparator: Normal hearing children without co-morbid or hearing-related problems were considered, and adults as a comparison.

Outcome: Pitch perception ability in children, tests that are used to assess these related parameters was studied, and all the included articles have the behavioral pitch assessing test materials.

3.2 Results of data extraction

Table 3.1 shows the aim, study design, details of the participants, testing method, stimulus-related information, and outcome of each study.

Table 3.1:

Study Characteristics of the selected articles

Author/s & Year	**Study design**	**Study aim**	**Population**	**Test parameter**	**Result**	**Discussion**
Deroche et al. (2016)	Experimental study	To study the difference between sensitivity to static and dynamic changes in pitch.	**4 groups**: • 21 normal hearing children • 23 children with CI • 18 normal hearing adults and • 4 adults with CI. **Chronological age:**	**1st exercise:** – Method: 1-interval, 2-alternative forced choice (1I-2AFC), – Stimulus level: At 65 dB SPL, – Stimulus duration: 300-ms, with 30-ms onset and offset ramps, and with the 300 ms interstimulus interval. – The F_0 varied at the rate of 0.5, 1, 2, 4, 8, 16, 32, 64, and	– All 18 normal hearing adults performed both tasks well. – Thresholds were higher (worse) for CI listeners than for normal hearing listeners. – The threshold s for children were higher than for adults.	– Adults performed better than children, and older children performed better than younger ones. But no clear role of chronological age was reported. – The absence of interaction between age and hearing status in both tests, both children and

			Normal hearing adults- 34.8 (11.4) years [21.2–50.9 years] Normal hearing children- 11.8 (3.4) years [6.1–18.1 years] CI children- 13.0 (3.0) years [8.1–17.9 years] CI adults - 57.2 (3.6) years [52.5–61.2 years]	128 semitones per second. – Task: listeners have to determine whethe r the presented stimulus was raising or lowering in pitch **2nd exercise:** – Method: 3-interval, 2-alternative forced choice (3I-2AFC). – Task: The listeners have to identify which sound was different from the reference sweep after hearing one reference sweep. – A test block had 140 trials, presented in random order and	– Age at implantation, length of CI experience, and age at a hearing loss, did not significantly influence the sensitivity. – Dynamic pitch sensitivity thresholds (in both tasks) were also correlated with static pitch sensitivity thresholds.	adults; had problems with dynamic pitch sensitivity. – The dynamic pitch task required more linguistic ability, so CI had a worse score.

				included 7 sweep rates by 2 directions (same or opposite) that tested 10 times each. – Sweep rates: 0.5, 1, 2, 4, 8, 16, and 32 semitones/sec for normal hearing and 2, 4, 8, 16, 32, 64, and 128 semitones/sec for CI listeners. – When the scale was inadequate, a second test was targeted on rates of 0.25-8 semitones/sec in a block of 120 trials, or only 0.5-8 semitones in a block of 100 trials.		

				– When time allowed, a 3rd, 4th, and 5th test block was also administered, on the direction task, the discrimination task, or both.		
Deroche et al. (2019)	Experimental study	To compare the lexical tone production and perception of CI recipients with that of normal hearing children.	• 40 CI children • 35 normal hearing (NH) children • Age range: 6.4 to 17.2 years.	**Production task:** – Children were asked to say the Chinese term "yan-jing," (symbolise "eyes" and "eyeglasses.") with the second syllable being said with Tone 1 and Tone 4 (a high-level tone and a high falling tone, respectively). – A recorder (Sony MZ-RH1) was used to record the signals	– Children with CIs didn't stress the second syllable as much as their NH peers. – NH children depended mainly on F_0 cues to identify the two tones, whereas CI children depended more on duration cues.	– Children with CI received the compression of dynamic range in the auditory feedback from their own recorded voice, due to this ability to detect small changes in loudness was affected. – Children with NH listened binaurally to the stimulus while children with CI

				– Adobe audition 3.0 program was used to divide signals into 400 ms. **Perception task:** – To get continuity in the perception of the words "yan-jenny" and "yong-jing," in a sequence between Tones 1 and 4, the slope of the F_0 contour and the duration of the stimulus were varied. – The slopes varied from −1, −0.8, −0.6, −0.4, −0.3, −0.2, and −0.1, to 0 octaves. – The durations varied from 40, 60,	– NH children made use of duration use alone when the pitch contours were ambiguous, – CI children made use of duration cues throughout all variations.	listened monaurally. This also might have affected the CI child's performance.

				80, 100, 120, and 140% of the initial duration. – These variations were carried out at an F_0 height of 120 Hz or 220 Hz. – Task: The participants were asked to identify whether a particular stimulus presented was "eyes" or "eyeglasses" by clicking on one of two answer buttons that were displayed on the computer screen. – One-interval, two-alternative forced-choice paradigm was used. – Stimulus level: 65 dB SPL.		

Fancourt et al. (2013)	Experimental study	To examine the developmental changes in the ability to detect pitch change and to differentiate the direction of a pitch change using pitch glides.	130 participants **Groups:** • 13= 5 years old children (Age range: 4.7-5.5 years) • 20= 6-year-old children (Age range: 5.7-6.5 years) • 19= 7year old children (Age range: 6.7-7.5 years) • 23= 8year old children (age range: 7.7-8.5 years) • 18= 9 year old children (age	– Method: 3 intervals 2 alternative forced choice methods. – Task: The listeners were asked to determine whether the 1st or 3rd interval is the same as the 2nd. – Targets were randomly presented in both the pitch change detection and direction discrimination tasks. – Participants were asked to respond verbally whether the "first" or "last" interval was the odd-one-out.	3 patterns of performance were observed: – "Good performer" pattern: correct response or approach to a near-threshold level, – "Compliant" pattern: cyclical variations in performance and progression toward the threshold – "Non-compliant" (most frequently	Inattention, confusion, or fatigue might have influenced the pitch detection and discrimination task in younger children

			range: 8.9-9.6 years) • 20= 10year old children (age range: 9.8-10.5 years) • 13= 11year old children (age range:10.7-11.6 years) • 4= 13 year old children (age range:13.0-13.1 years) • 13 adults- (age range: 18-41 years).		found in younger children): at floor level and typically did not progress from the first two levels of the task. – The capacity to detect a change in pitch didn't improve significantly through middle childhood, and it was already adult-like in children of	

					around 6 to 7 years.	
Tong et al. (2014)	Experimental design	The extent to which numerous acoustic factors such as pitch, contour, onset, and offset impact tone perception in young Cantonese children.	• 180 Cantonese children. 5 to 6 years of age (Mean age 5.10 years) • 80 Cantonese children. (Mean age: 11 years, SD: 4 months) • All participants were children with normal hearing	– monosyllables /Ji/ and /fu/ were produced in 8 minimum tonal contrasts – used 2 sets of 6 tones – randomly presented 12 target words (six each for the syllable /Ji/ and /fu/) – 96 monosyllables with 24 set of 4 tonal syllables having 6 Cantonese's tones were used. – All sets stimuli had 3 phonetic contexts:	– Children made fewer correct responses in the same contour with different pitch height conditions than in the different contour same pitch height condition. – children had higher accuracy rate on syllable /Ji/ than one syllable /fu/ – There was an effect of Phonetic	– Degree of F_0 onset difference correlated with children's perceptual performance on similar contoured tones. – The result showed that Cantonese children attend to the onset F_0 for the perception of similar contoured tones but use pitch contour to distinguish

				1) 8 sets of 4 words: consisting of the same rimes, different syllable onsets (SRDO, hereafter), 2) 8 sets of 4 words: same syllable onsets, different rimes (SODR, hereafter), and 3) 8 sets of 4 words: different syllable onsets, different rimes (DRDO). – Pictures were used to depict the words.	Context, with a significant decrease in tone discrimination performance: SRDO > SODR > DODR. – There was also an effect of Tone Contrast.	different-contoured tones. – Because of the interaction between phonetic segments and acoustic features of lexical tones, a perceptual difference of lexical tones were seen.
Alessandro et al. (2014)	Experimental	To measure the HI / DI test was clinically effective in children with CI to evaluate the	• 20 profoundly deaf children • 5 to 17 years (Mean age = 12 years, SD = 3.1)	– JND: adaptive staircase procedure was used. – DF (41 Hz at test start, range 0–214 Hz)	– LF pitch perception was poorer in many CI children than in their NH peers.	– Place and time-based cue were utilized by the HI tests because of the sweep of both F_0 and harmonics, so

		perception of low tone	• Mean duration of CI use: 94 months (SD = 42.7)	– Increased for an incorrect response and decreased for a correct one till the 50 % of the subject's psychometric curve. – If JND was not found within 100 trials, it was set to 220 Hz. – HI/DI tests were administered (part of Auditory Speech) – Sounds Evaluation (A§E) suite: used to assess LF pitch perception skills in CI users. – Task: same/different discrimination task – discriminate 2 complex tones: one	– A significant difference between NH and CI groups was present for both HI/DI tests. – Pitch perception in HI and DI tests differed significantly in both groups: responses were better for HI than for DI.	one or more harmonics tend to move to the adjacent channel and provide place cues for lower JND's. – In DI tests, sweep of only F_0 is present, so it used time-based cue; and a small change in F_0 will not lead to stimulation of different electrodes. – Therefore, HI had a better response than the DI test.

				intonating and one non-intonating.		
Deroche et al. (2012)	Experimental	To measure children's hearing abilities by measuring their psychophysical sensitivity to cues signaling changes in amplitude modulation rate (AMR) and changes in F_0.	• 9 male and 8 female, • Age range: 6.5- to 15.2-years • Normal hearing	– Method: 3-interval, 3-alternative-forced choice (3I3AFC) – constant stimuli were used. **AMR discrimination:** – Used broadband Gaussian white noise – Modulated sinusoidal signal at 100Hz – 7 Condition: 0, 2, 4, 6, 8, 10, and 12 semitones above 100 Hz. **F_0 discrimination:** – Broadband sine-phase harmonic complexes	– Children's sensitivity to F0 has not improved beyond 6 years. – Large individual differences across listeners were present; these differences did not vary systematically throughout 6–16 yr. – Thresholds were correlated across the two tasks and were about 9	– The sensitivity to pitch cues differences might be affected because of experience to musical training but the data was not collected. – Children with NH are less likely to perceive periodicity signals in the sinusoidally modulated temporal envelope.

				– Reference signals had a 100-Hz F_0. – Target signals had F_0s: 0,1=8,1=6,1=4,1=2, 1, and 2 semitones above 100 Hz. – Stimulus duration: 500 ms long and gated by 10-ms ramps – Stimulus level: at 65 dB SPL.	times finer for F_0 discrimination than for AMR discrimination	
Hegarty & Faulkner (2013)	Experimental study	To examine whether the low-frequency information from a hearing aid improves pitch and stress perception in English-speaking children with CIs.	• 9 children • Age range - 7.4 to 14.6 years (mean 10.2; SD 2.55) • At least 1 year of CI usage • At least 3 months hearing aid users.	**1. Adaptive threshold measurement** – Recorded synthesized sounds of the non-meaningful bisyllabic word. – Discriminating test—F0 (pitch high or low) or amplitude were	**1. Adaptive threshold measurement** – no significant difference in lower F_0 thresholds for both ranges were present in the bimodal condition.	– There was effect of bimodal stimulation on the perception of the pitch due to age and stimulus used in the study, this might have influenced the results – Better result obtained might

		To study whether CI users depend more on duration and amplitude signals to perceive pitch and stress.		altered to emphasize the 1st or 2nd syllable by way of a rise in pitch or increased amplitude. – Stimulus: pair of words (same or different regarding the emphasized syllable) – Stimulus duration: 300 ms duration and 600 ms of gap between each syllable. – Pitch: low or high (F_0) series, all syllables were synthesized with the same amplitude, F_0 in the stressed syllable varied in 64 logarithmic steps (from 4 % above baseline to 125%)	**Experiment 2: Focus sentence test** – Significant effect was seen only for speech and not for speaker. - mean correct score for sentences with a natural F_0 contour was higher than those with a synthesized F_0 contour. - The amplitude and duration cues were taken into consideration by children	be due to the usage of amplitude and durational cues – Mainly durational cues helped to access the stress and intonation consistently.

				– amplitude series: all syllables had the same constant F_0 contour, and amplitude difference between syllables varied in 1 dB steps (from 1 to 16 dB). **Experiment 2: Focus sentence test** – to assess intonation – Stimulus: connected and meaningful speech material, 2 adults recorded sentence stimuli. – Four sentences were recorded with a focus on one of three different positions.	when they perceived focus above chance. - Scores were not different for bimodal condition and CI alone condition. - Naturally produced sentences were perceived significantly better than synthesized sentences when only pitch cues were present. - Amplitude or duration cues contribute to the perception	

				i. neutrally produced version ii. rise F_0 contour iii. fall F_0 contour was imposed over the intended focused syllable using the PRAAT program. **l: Adaptive threshold measurement** – Method: 2 alternative forced choices (same/different task) – **Stimulus:** Recorded stimuli, 2-down, 1-up staircase procedure.	of stress and intonation.	

				– If subjects obtained 8/8 wrong or if 100 trials were completed before 10 reversals- procedure will end. **2: Focus sentence test** – 1 of the 4 documented sentences was presented, and selecting the picture representing the sentence was taken as a response. – 45 sentences with a pause after every 15 sentences were present.		

3.3 Quality Assessment

The Critical Appraisals Skills Programme (CASP) was used to assess the quality of the studies. It is a generic tool for appraising the strengths and limitations of any qualitative researchmethodology. It consists of 12 questions to assess the article in depth across each section to reduce bias. The questions in the tool are marked as “Yes”, “No” or “Can't tell” depending on the question's requirement. The results of the quality assessment forall of the selected studies are provided in Table 3.2.

Table 3.2

Results of the quality assessment for all of the selected studies: CASP Checklist – Diagnostic Test Study

AUTHORS AND YEAR	QUESTIONS													Total of Yes (Score)
	Section A: Are the results of the trial valid?					Section B: What are the results?					Section C: Will the results help locally?			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7		Q8		Q9	Q10	Q11	
							Q7a	Q7b	Q8a	Q8b				
Deroche et al. (2016)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	92%
Hegarty and Faulkner (2013)	Yes	Can't tell	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	84%
Deroche et al. (2019)	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	77%
Deroche et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	100%
Fancourt et al. (2013)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	92%
Tong et al. (2014)	Yes	Yes	Can't tell	No	Yes	Yes	No	No	No	No	Yes	Yes	Yes	53%
Alessandro et al. (2015)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	76%

NOTE:

Yes (green) No (red) Can't tell (amber)

*Questions for the following table are given below:

Section A: Are the results of the trial valid?

1. Was there a clear question for the study to address?
2. Was there a comparison with an appropriate reference standard?
3. Did all patients get the diagnostic test and reference standard?
4. Could the results of the test have been influenced by the results of the reference standard?
5. Is the disease status of the tested population clearly described?
6. Were the methods for performing the test described in sufficient detail?

Section B: What are the results?

7. What are the results?
8. How sure are we about the results? Consequences and cost of alternatives performed?

Section C: Will the results help locally?

9. Can the results be applied to your patients/the population of interest?
10. Can the test be applied to your patient or population of interest?
11. Were all outcomes important to the individual or population considered?

From the CASP, as depicted in Table 3.2, it was found that all the studies were of good quality. 9 out of 12 questions were answered as "Yes," for all the studies, indicating good quality judgment. The research questions were addressed in all the studies, and all the participants included in the study were assessed for pitch and pitch-related factors.

Chapter 4

DISCUSSION

The present study aimed to check the several tests designed to assess pitch perception in children with normal hearing and hearing impairment. Also, to assess the efficiency of these tests in assessing the pitch perception in children.

4.1 Different tests for assessment of perception of pitch

4.2 The efficacy of the test for assessment of perception of pitch

4.1 Different tests for assessment of perception of pitch

The study by Deroche et al. (2016) aimed to determine the discrimination of harmonic complexes based on a linear rising or falling fundamental frequency. Correct percent scores were calculated in one or three intervals, two-alternative forced choice tasks. Sweep rates were modified for each individual on a logarithmic scale to cover the entire psychometric function range. The listener was given a single sweep and asked to identify whether the pitch was rising or falling and the second task used 3-interval, 2-alternative forced choice (3I-2AFC). The listeners were given one reference sweep, rising or falling, and were instructed to indicate which interval sounded different from the reference sweep.

In the study by Hegarty and Faulkner (2013), two experiments involved 9 participants who had cochlear implants (CI) and hearing aids for bimodal stimulation. The first experiment assessed the barely audible F_0 (pitch) variation and amplitude for a word that resembled speech, “baba”. The children’s ability to recognize attention in both real and manipulated phrases was tested in the second experiment. The authors studied whether low-frequency information improves English-speaking CI children's perception of stress and intonation. Adaptive threshold measurement and focus sentence test were used as testing materials. The procedure was to discriminate the F_0 and amplitude of the non-meaningful disyllables in focus sentences with four sentences with stress on each possible position in a sentence. Adaptive measurement had stimuli based on the 2 down 1 up staircase procedure. And the focus sentence had a response taken when the subject selected the picture representing the focus.

Fancourt et al. (2013) studied changes in the developmental ability to detect a change in pitch and to discriminate the direction of a pitch change using pitch glides in children. Adaptive tracking approaches were used. The adaptive staircase profile plots screening function allowed the elimination of inattentive participants, and the use of an odd-one-out paradigm removed the necessity for participants to employ semantic labels while determining the direction of a pitch change. Deroche et al. (2019) compared the lexical tone production in CI recipients to that of normal hearing children and lexical tone perception in the same subjects. Lexical tones from CI recipients and their normal hearing peers were captured. A disyllabic term called ‘yan jing’ was required of each participant, with the first syllable being said as Tone 3 (a low dipping tone) and the second syllable either being pronounced as Tone 1 (a high-level tone, meaning “eyes”) or as Tone 4 (a high falling tone, meaning “eyeglasses”).

Deroche et al. (2012) assessed both the amplitude modulation rate (AMR) discrimination (experiment 1) and the F_0 discrimination (experiment 2) tasks using the odd-man-out paradigm to assess the psychophysical sensitivity to cues indicating changes in AMR and changes in F_0. The test methodology was created as an easy video game with picture-pointing responses and feedback, known to enhance accuracy. The percentage of correct scores were calculated for the discrimination of sinusoidal AMR of broadband noise and the F_0 of broadband sine-phase harmonic complexes. Both the reference F_0 and the reference AMR were set to 100 Hz. A user-friendly interface made it easier for listeners to focus on the task.

Tong et al. (2014) used eight minimum pairs of tonal contrasts that were either presented in the same phonetically relevant context or other contexts. The study examined the effects of acoustic cues (such as pitch height, pitch contour, and pitch onset and offset) and phonetic context cues (such as syllable onsets and rimes) on lexical tone perception (different syllables onsets and rimes). Children were taught how to identify and distinguish between tones.

A study by Alessandro et al. (2015) compared and assessed the application of pitch perception tests between individuals with CI, and normal hearing (NH) children . The evaluation of auditory speech sounds included measuring low-frequency pitch perception using the Harmonic Intonation & Disharmonic Intonation tests, based on two successive complex tones such as intonating and non-intonating. The complex harmonic signal of F_0 200 Hz and three higher harmonics, provided at low intensity than F_0, were used to represent the non-intonating (-6 dB at $2F_0$, -12 dB at $3F_0$, and -18 dB at $4F_0$).

4.2 The efficacy of the test for assessment of perception of pitch

According to Deroche et al. (2016), children with CI have substantially greater thresholds for sensitivity to dynamic changes in pitch than their NH peers. These thresholds were equivalent to sweeps covering 1.6 and 9 semitones, respectively, in the 300-ms time window. The dynamic thresholds indicate F_0 ranges are many times larger than the static sensitivity. For NH children, static thresholds were roughly 10-20 cents, while CI children were 2-3 semitones. The study showed that the thresholds of individuals with CI and NH overlapped to a small extent. According to the authors, the best pitch sensitivity a CI user could obtain may be constrained by the envelope coding strategies related to present CI processing. Two children with CI had thresholds between 8 and 16 semitones/sec, which is still within the range of NH variability, while four NH children had extremely high thresholds. Adults and children with CI have different pitch sensitivity levels, but the deficits in dynamic pitch sensitivity are in the average range; it was the same for both groups. Although chronological age has a definite influence, no additional experience-related characteristics are unique to CI users. The fact that age and hearing status did not interact in either task leads one to conclude that there is little difference between the two. Considering the older children, this sensitivity appears realistic given this investigation's mean thresholds for CI adult and CI child individuals.

Hegarty and Faulkner (2013) suggested that duration cues might have been the most useful and reliable for perceiving stress and intonation when pitch and amplitude signals were unavailable. There was no consistent pattern in the children who benefited or could not benefit from bimodal stimulation for understanding stress and intonation. No difference between bimodal stimulation and cochlear implant perception of stress and intonation had been reported. Adaptive measurement had stimuli based on the 2 down 1 up staircase procedure. The focus sentence test had a response taken when the subject selected the picture representing the focus. The result of the study from the first hypothesis was that the bimodal condition would improve children’s perception of stress and intonation compared to the CI alone condition and found no higher score for bimodal stimulation than a cochlear implant alone. Naturally produced sentences had better scores than manipulated focus sentences which showed that amplitude or pitch cues contributed to a better perception of stress and pitch. The CI children were able to perceive stress and intonation through the use of amplitude and duration signals when pitch signals were not available.

The study findings from Fancourt et al. (2013) showed that the overall pattern of the sensitivity of the direction of pitch shifts could be well differentiated at the age of 11 years or above; fine-grained pitch-change detection is adult-like in children aged 6 to 7 years. The newborns and young children can identify the direction of changes in pitch. Steady improvements in the thresholds for pitch-direction discriminations were observed in children up to around 11 years, at which point they became similar to the thresholds observed in adults. The young children can differentiate the direction of pitch shifts, but they also show that the sensitivity with which those discriminations may be made increases with age.

Deroche et al. (2019) findings help compensate for the low functional spectrum resolution; CI users adopt alternate acoustic dimensions that co-vary with F_0 contour. Their reliance on F0 rather than duration cues predicted the same children's performance when they were asked to identify lexical tones in a sample of 40 naturally spoken words. In connected speech, the four lexical tones show less difference in duration. Because duration cues may not be very useful at the sentence level, the degraded F_0 contour may still provide more accurate data in ecological conditions. Children with CI frequently preferred length cues and had the most monotonous tone production. Even though this clinical population has poor auditory feedback, the outcome suggests that perception and production are reasonably connected. They concluded that the difference between Tone 1 and Tone 4 allowed them to study the shifts in perceptual weighting between two auditory variables (F_0 and duration) that are known to have a role in Mandarin Chinese lexical tone identification. Considering that the selected bi-syllabic words with two lexical tones have very easy linguistic meanings, this Tone 1 vs. Tone 4 comparison is also appropriate for target populations and relatively young listeners (i.e., eyes vs. eyeglasses).

Deroche et al. (2012b) indicate that young children exhibit more differences than 8-year-old children and adults. The threshold was around 1.6 semitones at 70.7 % performance on a 2I-2AFC task with an AMR reference of 128 Hz. Individual children showed greater sensitivity to pure temporal pitch than children with NH. According to the current study's findings, children's sensitivity to F_0 does not consistently improve beyond 6 years. Children actively tried to do well, as they were more cautious in their responses as the task complexity increased. It seems that the approach was successful in enhancing sustained attention. Individual children exhibit a better sensitivity to purely temporal pitch than the NH children of the present study. If so, how similar they are to the sensitivity of NH children to $F_{0.}$ The performance at the threshold was between 64 and 66.6 %, and d_0 was between 1.043 and 1.134 since the lapse rate was less than 5.5 %. The criteria corresponded to a performance between 64.8 percent and 66.6 percent, and d_0 was between 1.07 and 1.134 for four children whose lapse rate was less than 4 %.

According to research by Tong et al. (2014b), Cantonese children pay attention to the F_0 onset for the perception of tones with comparable contours and the F_0 contour for the perception of tones with distinct contours. The F_0 onset is another significant auditory cue to take into account in the model of tone perception, particularly about cue-weighting in tone perception, according to the study's preliminary findings. There was a main effect of Tonal Syllable, where children had a higher accuracy rate on the syllable /ji/ than on the syllable /fu/, and the main effect of Pitch Contour, where children made very few correct responses in the same contour different pitch height condition than in the different contour same. In contrast, children gave more accurate answers to contrastive tones with varied contours and the same height for the syllable /fu/ than tones with the same contour and different heights. Children performed differently on eight-tone contrasts for the syllable /ji/. The mean accuracy for the eight-tone contrasts for the word "fu" varied substantially. Low increasing and low level performed worse than any other contrasts among the children. Children's tone perception performance was much more in connection with the pattern of different F_0 values at onset for these four tone contrasts across syllables, according to the children's response accuracies for the four tone contrasts (61.3 %, 76.3 %, 92.04 %, and 79.63 %, respectively). The performance of children in identifying tones and the onset and offset differences of tone contrasts were correlated. The results also showed no significant correlation between pitch offset difference and tone identification. Still, that pitch onset difference was strongly associated with children's tone identification skills (r =.80, p .05). These findings showed that Cantonese children utilize pitch contour to discriminate between tones with distinct contours while attending to the onset F_0 for the perception of tones with identical contours. One significant finding was that Cantonese children could identify distinct tones with identical contours using the F_0 onset as a signal. Additionally, it demonstrates that Cantonese children pay attention to the onset F_0 for the perception of tones with comparable contours and the F_0 contour for the perception of tones with distinct contours. The perception of lexical tones involves the interaction processing of phonemes and tonemes, which has a context impact.

The study by Alessandro et al. (2015) indicated that LF hearing loss patients performed poorly on both tests, with much worse DI test results in those who used a CI with an EAS processor than those who just received electrical stimulation. While the

DI test offers more varied results on phase locking and TFS processing capacity, the HI test assesses the availability of both place cues and TFS. There is evidence that cortical neurons that are tuned to pitch, exist beyond the primary auditory cortex, even though it is known that both frequency and time domain information is present in the peripheral auditory system and that the frequency map is maintained to some extent throughout the auditory system up to primary auditory cortex (McDermott & Oxenham, 2008). According to the findings of the current study, the majority of CI receivers had abnormal outcomes, which supported inadequate TFS processing of the CI. The present study's examination of correlations found no connection between the CI group's pitch perception ability, chronological age, or the age of implantation. A small percentage of NH children under 8.5 years old had significantly greater JNDs, and some had JNDs regarded abnormal in the adult NH population. However, in the NH group, chronological age had a major effect on DI performance.

CHAPTER 5

SUMMARY AND CONCLUSION

The systematic review summarizes the various tests used to assess pitch perception and its efficiency in children with normal hearing and hearing impairment from the existing research findings. The search for the articles began with finalizing appropriate keywords and using them to search in various search engines. Later the articles found were screened at various stages. At the end of all the screening stages, studies were collected, and those relevant to our research questions were taken up. The entire procedure of searching and identifying articles was done using PRISMA. Seven studies were short-listed at the end of this process. The full-length articles of the seven studies were read through, and the tests and procedures used in the articles were analyzed. Studies that explained tests for pitch perception to assess children with normal hearing- and hearing impairment were considered for the review.

The tests that can be used for assessing pitch perception in children with normal hearing- and hearing-impaired are: Up-Down/ Rising – lowering procedure, tonal contrasts, just noticeable difference (JND), pitch sweeps, lexical tone perception, direction and perception of pitch glides, focus sentences are used in our reviewed study articles.

The review article showed that children with cochlear implants performed worse than normal hearing in pitch perception tests but performed better than hearing aid users in pitch perception tests. Children tend to develop adult-like pitch perception characteristics around 11 years of age. In the absence of pitch cues, individuals with hearing loss rely on amplitude and durational cues to perceive the complex stimuli.

To conclude, this systematic review will help compare the pitch perpetual test results of the individuals with hearing impairment, those using hearing aids or cochlear implants, and those with normal hearing. It would help audiologists to assess and manage the perception of pitch-related aspects for individuals with hearing impairment.

5.1 Clinical Implication of the Study

- This review provides evidence for the audiologist to understand the pitch perception tests for children.
- The review also provides evidence for the audiologist to understand the factors influencing and better efficacy in children.
- Caregivers and parents should be advised to get early implantation and rehabilitation to improve their child's pitch perception ability.
- Helps audiologists in assessing and management of individuals with hearing impairment with the aspects of pitch perception.

5.2 Future Direction

- More studies are needed to comprehensively understand the pitch perception ability in individuals with hearing impairment.
- It is necessary to evaluate the pitch perception ability in new CI recipients who are implanted early & with more advanced CI technologies.
- Studies need to be reviewed on electrophysiological evidence to assess pitch perception in individuals with normal hearing and hearing impairment.
- Not many studies in the Indian context explore pitch perception abilities in children.

References

Bachem, A. (1950). Tone height and tone chroma as two different pitch qualities. *Acta Psychologica*.

Beerends, J. G., & Houtsma, A. J. (1989). Pitch identification of simultaneous diotic and dichotic two-tone complexes. *The Journal of the Acoustical Society of America*, *85*(2), 813–819. https://doi.org/10.1121/1.397974

Bernstein, J. G. W., & Oxenham, A. J. (2006). The relationship between frequency selectivity and pitch discrimination: Sensorineural hearing loss. *The Journal of the Acoustical Society of America*, *120*(6), 3929–3945. https://doi.org/10.1121/1.2372452

Bernstein, J. G., & Oxenham, A. J. (2003). Pitch discrimination of diotic and dichotic tone complexes: Harmonic resolvability or harmonic number? *The Journal of the Acoustical Society of America*, *113*(6), 3323–3334.

Bernstein, J. G., & Oxenham, A. J. (2003). Pitch discrimination of diotic and dichotic tone complexes: Harmonic resolvability or harmonic number? *The Journal of the Acoustical Society of America*, *113*(6), 3323–3334.

Brokx, J. P. L., & Nooteboom, S. G. (1982). Intonation and the perceptual separation of simultaneous voices. *Journal of Phonetics*, *10*(1), 23-36.

Boëx, C., Baud, L., Cosendai, G., Sigrist, A., Kós, M.-I., & Pelizzone, M. (2006). Acoustic to electric pitch comparisons in cochlear implant subjects with residual hearing. *Journal of the Association for Research in Otolaryngology: JARO*, *7*(2), 110–124. https://doi.org/10.1007/s10162-005-0027-2

Burns, E. M., & Viemeister, N. F. (1981). Played-again SAM: Further observations on the pitch of amplitude-modulated noise. *The Journal of the Acoustical Society of America*, *70*(6), 1655-1660.

Burton, R. (2015). The elements of music: what are they, and who cares. In Music: Educating for Life. ASME XXth National Conference Proceedings (pp. 22-28). Parkvill, VIC, Australia: Australian Society for Music Education.

Cariani, P. A., & Delgutte, B. (1996). Neural correlates of the pitch of complex tones. I. Pitch and pitch salience. *Journal of Neurophysiology*, *76*(3), 1698–1716. https://doi.org/10.1152/jn.1996.76.3.1698

Critical Appraisal Skills Programme (2018). CASP CHECKLISTS – CASP – Critical Appraisal Skills Programme: Diagnostic Study Checklist. https://casp-uk.net/casp-tools-checklists/ assessed on 24th March 2022.

Clarkson, M. G., & Clifton, R. K. (1985). Infant pitch perception: Evidence for responding to pitch categories and the missing fundamental. *The Journal of the Acoustical Society of America*, *77*(4), 1521–1528.

Cutler, A., Dahan, D., & Van Donselaar, W. (1997). Prosody in the comprehension of spoken language: A literature review. Language and speech, 40(2), 141-201.

Dai, H. (2000). On the relative influence of individual harmonics on pitch judgment. *The Journal of the Acoustical Society of America*, *107*(2), 953–959.

Deroche, M. L. D., Kulkarni, A. M., Christensen, J. A., Limb, C. J., & Chatterjee, M. (2016). Deficits in the Sensitivity to Pitch Sweeps by School-Aged Children

Wearing Cochlear Implants. *Frontiers in Neuroscience*, *10*. https://doi.org/10.3389/fnins.2016.00073

Deroche, M. L., Lu, H. P., Kulkarni, A. M., Caldwell, M., Barrett, K. C., Peng, S. C., ... & Chatterjee, M. (2019). A tonal-language benefit for pitch in normally-hearing and cochlear-implanted children. Scientific reports, 9(1), 1-12. https://doi.org/doi: 10.1038/s41598-018-36393-1

Deroche, M. L., Lu, H. P., Limb, C. J., Lin, Y. S., & Chatterjee, M. (2014). Deficits in the pitch sensitivity of cochlear-implanted children speaking English or Mandarin. *Frontiers in Neuroscience*, *8*, 282. https://doi.org/doi: 10.3389/fnins.2014.00282

Deroche, M. L. D., Zion, D. J., Schurman, J. R., & Chatterjee, M. (2012). Sensitivity of school-aged children to pitch-related cues. *The Journal of the Acoustical Society of America*, *131*(4), 2938–2947. https://doi.org/10.1121/1.3692230

Dincer D'Alessandro, H., Filipo, R., Ballantyne, D., Attanasio, G., Bosco, E., Nicastri, M., & Mancini, P. (2014). Low-frequency pitch perception in children with cochlear implants in comparison to normal hearing peers. *European Archives of Oto-Rhino-Laryngology*, *272*(11), 3115–3122. https://doi.org/10.1007/s00405-014-3313-y

Edwards, S. L. (2014). Pitch perception, production and musical development of hearing impaired children [PhD Thesis]. UCL (University College London).

Eimas, P. D., Siqueland, E. R., Jusczyk, P., & Vigorito, J. (1971). Speech perception in infants. *Science (New York, N.Y.)*, *171*(3968), 303–306. https://doi.org/10.1126/science.171.3968.303

Fancourt, A., Dick, F., & Stewart, L. (2013). Pitch-change detection and pitch-direction discrimination in children. *Psychomusicology: Music, Mind, and Brain*, *23*(2), 73–81. https://doi.org/10.1037/a0033301

He, C., & Trainor, L. J. (2009). Finding the pitch of the missing fundamental in infants. *Journal of Neuroscience*, *29*(24), 7718–8822. doi:10.1523/JNEUROSCI.0157-09.2009

Hegarty, L., & Faulkner, A. (2013). The perception of stress and intonation in children with a cochlear implant and a hearing aid. *Cochlear Implants International*, *14*(sup4), 35–39. https://doi.org/10.1179/1467010013Z.000000000132

Hepper, P. (1992). Fetal psychology: An embryonic science. In J. G. Nijhuis (Ed.), *Fetal Behaviour: Developmental and Perinatal Aspects* (pp. 129–156). Oxford University Press.

Hepper, P. G., & Shahidullah, B. S. (1994). Development of fetal hearing. *Archives of Disease in Childhood. Fetal and Neonatal Edition*, *71*(2), F81-87. https://doi.org/10.1136/fn.71.2.f81

Houtsma, A. J. M., & Smurzynski, J. (1990). Pitch identification and discrimination for complex tones with many harmonics. *The Journal of the Acoustical Society of America*, *87*(1), 304–310.

Kaernbach, C., & Bering, C. (2001). Exploring the temporal mechanism involved in the pitch of unresolved harmonics. *The Journal of the Acoustical Society of America*, *110*(2), 1039-1048.

Key membership and implied harmony in Western tonal music: Developmental perspectives | SpringerLink. (1998). Retrieved August 11, 2022, from https://link.springer.com/article/10.3758/BF03213891

Kuhl, P. K., Williams, K. A., Lacerda, F., Stevens, K. N., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science (New York, N.Y.)*, *255*(5044), 606–608. https://doi.org/10.1126/science.1736364

Kuo, Y. C., Rosen, S., & Faulkner, A. (2008). Acoustic cues to tonal contrasts in Mandarin: Implications for cochlear implants. *The Journal of the Acoustical Society of America*, *123*(5), 2815-2824.

Lambert, M. (2017). *Pitch Perception in Preschool-Age Children who are Deaf or Hard of Hearing*. All Graduate Plan B and other Reports. 918. https://digitalcommons.usu.edu/gradreports/918.

doi: https://doi.org/10.26076/665e-01e4

Lamont, A. (1998b). Music, education, and the development of pitch perception: The role of context, age and musical experience. *Psychology of Music*, *26*(1), 7–25. https://doi.org/10.1177/0305735698261003

McDermott, J. H., & Oxenham, A. J. (2008). Music perception, pitch, and the auditory system. *Current Opinion in Neurobiology*, *18*(4), 452–463. doi: 10.1016/j.conb.2008.09.005

Moore, B. C. (2008). The role of temporal fine structure processing in pitch perception, masking, and speech perception for normal-hearing and hearing-impaired people. *Journal of the Association for Research in Otolaryngology*, *9*(4), 399–406.

Moore, B. C. (2012). *An introduction to the psychology of hearing*. Brill.

Moore, B. C., Glasberg, B. R., & Peters, R. W. (1985). Relative dominance of individual partials in determining the pitch of complex tones. *The Journal of the Acoustical Society of America*, *77*(5), 1853–1860.

Morrongiello, B. A., & Roes, C. L. (1990). Developmental changes in children's perception of musical sequences: Effects of musical training. *Developmental Psychology*, *26*(5), 814–820. https://doi.org/10.1037/0012-1649.26.5.814

Murray, I. R., & Arnott, J. L. (1993). Toward the simulation of emotion in synthetic speech: A review of the literature on human vocal emotion. *The Journal of the Acoustical Society of America*, *93*(2), 1097-1108.

Music, Education, and the Development of Pitch Perception: The Role of Context, Age and Musical Experience—Alexandra Lamont, 1998. (n.d.-a). Retrieved August 11, 2022, from https://journals.sagepub.com/doi/10.1177/0305735698261003

Nazzi, T., Floccia, C., & Bertoncini, J. (1998). Discrimination of pitch contours by neonates. *Infant Behavior and Development*, *21*(4), 779–784.

Olsen H. F., (1967). Music, Physics, and Engineering. Dover publication. P. 249

Oxenham, A. J. (2018). How we hear: The perception and neural coding of sound. *Annual Review of Psychology*, *69*, 27. https://doi.org/10.1146/annurev-psych-122216-011635

Plack, C. J., & Oxenham, A. J. (2005). The psychophysics of pitch. In *Pitch* (pp. 7–55). Springer.

Plack, C. J., Barker, D., & Hall, D. A. (2014). Pitch coding and pitch processing in the human brain. *Hearing Research*, *307*, 53–64. https://doi.org/10.1016/j.heares.2013.07.020

Plomp, R. (1967). Pitch of complex tones. *The Journal of the Acoustical Society of America*, *41*(6), 1526–1533.

Ritsma, R. J. (1967). Frequencies dominant in the perception of the pitch of complex sounds. *The Journal of the Acoustical Society of America*, *42*(1), 191–198.

Rose, J. E., Brugge, J. F., Anderson, D. J., & Hind, J. E. (1967). Phase-locked response to low-frequency tones in single auditory nerve fibers of the squirrel monkey. *Journal of Neurophysiology*, *30*(4), 769–793.

Shackleton, T. M., & Carlyon, R. P. (1994). The role of resolved and unresolved harmonics in pitch perception and frequency modulation discrimination. *The Journal of the Acoustical Society of America*, *95*(6), 3529–3540.

Shofner, W. P. (2005). Comparative aspects of pitch perception. In *Pitch* (pp. 56–98). Springer.

Straatman, L., Rietveld, T., Beijen, J., Mylanus, E., & Mens, L. (2010). Perception of prosody in children fitted bimodally with a cochlear implant and a hearing aid. *Journal of The Acoustical Society of America 128:* 1884–1895. doi: 10.1121/1.3474236

Todd, A., Mertens, G., Van de Heyning, P., & Landsberger, D. (2017). Encoding a Melody Using Only Temporal Information for Cochlear-Implant and Normal-Hearing Listeners. *Trends in Hearing*, *21*, 233121651773974. https://doi.org/10.1177/2331216517739745

Tong, X., McBride, C., & Burnham, D. (2014). Cues for Lexical Tone Perception in Children: Acoustic Correlates and Phonetic Context Effects. *Journal of Speech, Language, and Hearing Research*, *57*(5), 1589–1605. https://doi.org/10.1044/2014_JSLHR-S-13-0145

Townshend, B., Cotter, N., Van Compernolle, D., & White, R. L. (1987). Pitch perception by cochlear implant subjects. *The Journal of the Acoustical Society of America*, *82*(1), 106–115. https://doi.org/10.1121/1.395554

Trehub, S. E., Cohen, A. J., Thorpe, L. A., & Morrongiello, B. A. (1986). Development of the perception of musical relations: Semitone and diatonic structure. *Journal of Experimental Psychology: Human Perception and Performance*, *12*(3), 295. https://doi.org/10.1037/0096-1523.12.3.295

Vaerenberg, B., Pascu, A., Del Bo, L., Schauwers, K., De Ceulaer, G., Daemers, K., Coene, M., & Govaerts, P. J. (2011). Clinical assessment of pitch perception. *Otology & Neurotology*, *32*(5), 736–741.

Walinga, J., & Stangor, C. (2014). *Introduction to psychology-1st canadian edition*.

Walker, K. M. M., Bizley, J. K., King, A. J., & Schnupp, J. W. H. (2011). Cortical encoding of pitch: Recent results and open questions. *Hearing Research*, *271*(1–2), 74–87. https://doi.org/10.1016/j.heares.2010.04.015

Wang, S., Liu, B., Zhang, H., Dong, R., Mannell, R., & Newall, P. (2013). Hearing-impaired listeners and cochlear implant users. *Acta Otolaryngol*, *133*, 47-54. https://doi.org/doi: 10.3109/00016489.2012.705438

Yost, W. A. (2009). Pitch perception. *Attention, Perception & Psychophysics*, *71*(8), 1701–1715. https://doi.org/10.3758/APP.71.8.1701