THE ANALYSIS MULTIFREQUENCY TYMPANOMETRY AMONG MALAY CHILDREN AGED 1-4 YEARS OLD

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THE ANALYSIS OF MULTIFREQUENCY TYMPANOMETRY AMONG MALAY CHILDREN AGED 1-4 YEARS OLD

By

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Thesis submitted in fulfilment of the requirements for the degree of Bachelor of Health Sciences (Honours) Audiology

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CERTIFICATE

This is to certify that the dissertation entitled "The Analysis of Multifrequency Tympanometric Parameters Among Malay Toddlers" is original research work undertaken by Nur Afiqah Binti Adnan from January 2025 to August 2025. We have reviewed this dissertation and are satisfied that it meets the required standards of scholarly presentation. We further confirm that it is adequate in scope and quality to be submitted in partial fulfilment of the requirements for the degree of Bachelor of Health Sciences (Honours) in Audiology.

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DECLARATION

I hereby declare that this work is the result of my own independent research and effort. All data and findings presented are derived from my investigation, and any ideas, quotations, or contributions from the work of others have been duly acknowledged following the standard referencing practices of the discipline. I further confirm that this dissertation has not been submitted, in whole or in part, for the award of any other degree at this or any other institution.

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LIST OF SYMBOLS

%	Percent
<	More than/ Larger than
>	Less than/ Smaller than
=	Equal
+	Positive value
_	Negative value
cm^3	Cubic centimetre
daPa	Decapascal
dBHL	Hearing level in decibels
dBSPL	Sound pressure level in decibels
Hz	Hertz
K	Kilo
mmho	Millimho
P	Probability value (p-value)
R	Correlation coefficient (r-value)
SD	Standard deviation
V_{ec}	Equivalent ear canal volume
Y_{tm}	Static compensated admittance

LIST OF ABBREVIATIONS

AC	Air conduction
ANOVA	Analysis of variance
AOM	Acute otitis media
ASHA	American Speech and Hearing Association
B	Conductance
CHL	Conductive hearing loss
CI	Confidence interval
COI	Conflict of interest
DPOAE	Distortion product otoacoustic emissions
ECV	Ear canal volume
ENT	Ear, nose, and throat
ET	Eustachian tube
G	Susceptance
GSI	Grason-Stadler Incorporated
HPUSM	Hospital Pakar Universiti Sains Malaysia
ICC	Intraclass correlation coefficient
JASP	Jeffreys's Amazing Statistics Program
JEPeM	Jawatankuasa Etika Penyelidikan Manusia
SNHL	Sensorineural hearing loss

LIST OF ABBREVIATIONS

MEE	Middle ear effusion
MFT	Multifrequency tympanometry
MHL	Mixed hearing loss
OAE	Otoacoustic emissions
OME	Otitis media with effusion
PPSK	Pusat Pengajian Sains Kesihatan
SA	Static admittance
TM	Tympanic membrane
TPP	Tympanometric peak presssure
TW	Tympanometric width
USM	Universiti Sains Malaysia

ABSTRAK

Timpanometri menggunakan nada probe 226 Hz lazimnya digunakan sebagai ujian bukan invasif yang sangat baik dengan kepekaan dan pengkhususan yang tinggi bagi menilai fungsi telinga tengah. Bagi meningkatkan kepekaan dalam mengesan patologi telinga tengah, penggunaan kepelbagaian frekuensi timpanometri disyorkan. Kajian ini menyiasat kepelbagaian frekuensi timpanometri (226 Hz, 678 Hz dan 1000 Hz) dalam kalangan kanak-kanak Melayu berumur 1–4 tahun untuk menilai fungsi telinga tengah serta menyediakan nilai rujukan awal bagi populasi ini. Menggunakan reka bentuk keratan rentas, seramai 38 orang kanak-kanak (76 telinga) telah direkrut daripada pusat jagaan harian dan klinik audiologi di Kelantan, Malaysia. Semua peserta menjalani saringan pendengaran termasuk otoskopi, DPOAE, ujian saringan refleks akustik, dan seterusnya timpanometri multifrekuensi.

Keputusan kajian menunjukkan kebolehpercayaan uji–ulang (test–retest) yang sangat baik merentasi semua frekuensi prob (226 Hz, 678 Hz dan 1000 Hz) seperti yang ditunjukkan oleh pekali korelasi antara kelas (ICC). Parameter timpanometri yang dinilai termasuk isi padu salur telinga (ECV), statik admitan (SA), tekanan puncak timpanometri (TPP) dan kelebaran timpanometri (TW). Bagi frekuensi 226 Hz, ICC berada dalam julat 0.765 hingga 0.976; bagi 678 Hz dalam julat 0.903 hingga 0.998; dan bagi 1000 Hz dalam julat 0.821 hingga 0.979. Ujian Kruskal–Wallis menunjukkan ECV dan SA berubah secara signifikan antara frekuensi prob. Secara khusus, ECV lebih tinggi pada 678 Hz berbanding 226 Hz, manakala nilai SA berbeza secara signifikan antara semua pasangan frekuensi. Sebaliknya, TPP tidak menunjukkan perbezaan signifikan merentasi frekuensi.

Analisis korelasi Spearman mendapati bahawa dalam kalangan kanak-kanak Melayu berumur 1–4 tahun, ECV dan SA meningkat sedikit dengan pertambahan usia, dengan korelasi paling kuat bagi SA pada 678 Hz. Sebaliknya, usia tidak memberikan kesan ketara terhadap TPP dan TW kerana kedua-duanya menunjukkan korelasi negatif yang lemah dan tidak signifikan. Peningkatan ECV dan SA selari dengan usia menunjukkan bahawa apabila kanak-kanak Melayu membesar, saiz salur telinga dan keanjalan telinga tengah mereka juga bertambah. Hal ini mencerminkan perkembangan anatomi dan fisiologi telinga tengah yang normal dalam tempoh awal kanak-kanak.

Dapatan ini menyokong kepentingan klinikal penggunaan parameter timpanometri multifrekuensi dalam mengenal pasti ciri telinga tengah dalam kalangan kanak-kanak kecil serta menyediakan data rujukan awal khusus bagi populasi pediatrik Melayu. Namun demikian, kajian berskala lebih besar yang melibatkan kumpulan etnik yang lebih pelbagai diperlukan untuk membangunkan piawaian normatif yang lebih menyeluruh.

ABSTRACT

Tympanometry using 226 Hz probe tone is commonly employed as an excellent non-invasive test with high sensitivity and specificity used to assess middle ear function. To increase sensitivity in detecting middle ear pathology, multifrequency tympanometry is recommended. This study investigated multifrequency tympanometry (226 Hz, 678 Hz, and 1000 Hz) in Malay children aged 1–4 years to evaluate middle ear function and to provide preliminary reference values for this population. Using a cross-sectional design, 38 children (76 ears) were recruited from daycare centers and audiology clinics in Kelantan, Malaysia. All participants underwent hearing screening including otoscopy, DPOAE, and screening acoustic reflex testing followed by multifrequency tympanometry.

The results of tympanometric parameters showed excellent test–retest reliability across all probe frequencies (226 Hz, 678 Hz and 1000 Hz), as indicated by intraclass correlation coefficients (ICCs). The tympanometry parameters included ear canal volume (ECV), static admittance (SA), tympanometric peak pressure (TPP) and Tympanometric width (TW). Using 226 Hz, ICCs ranged from 0.765 to 0.976, using 678 Hz ICCs ranged from 0.903 to 0.998 and 1000 ranged from 0.821 to 0.979. The Kruskal–Wallis tests showed that ear canal volume (ECV) and static admittance (SA) changed significantly across probe frequencies. Specifically, ECV was higher at 678 Hz compared to 226 Hz, and SA values were significantly different between all frequency pairs. In contrast, tympanometric peak pressure (TPP) did not show any significant differences across frequencies.

Correlation using Spearman's correlation analyses showed that in Malay toddlers aged 1–4 years, ECV and SA slightly increased with age, with the strongest correlation for

SA at 678 Hz. In contrast, age had little effect on TPP and TW, as these showed weak and non-significant negative correlations. Indicating the increase in ECV and SA with Age suggests that as Malay toddlers grow, their ear canal size and middle ear compliance also increase. This reflects normal anatomical and physiological development of the middle ear system during early childhood. These findings support the clinical value of tympanometry parameters in identifying middle ear characteristics in young children and provide preliminary reference data specific to the Malay paediatric population. However, larger studies involving diverse ethnic groups are needed to establish comprehensive normative standards.

CHAPTER 1

INTRODUCTION

1.1 Study Background

Children between the age 1 and 4 years old are in the golden period for speech and language acquisition, a critical developmental stage that lays the foundation for communication skills. While many newborns successfully pass initial hearing screenings, a study involving children over the age of six revealed that although 80.7% had normal hearing at the time of screening, 27.5% exhibited middle ear conditions that could potentially result in moderate hearing loss. (Yamamah et al., 2012). Children with hearing loss are more likely to experience delays in speech and language development, social isolation, poor academic performance, and behavioural issues. These challenges can significantly impact their overall cognitive, emotional, and social development if not addressed early.

Therefore, it is crucial for children to undergo early hearing screening in children to identify any hearing abnormalities that could hinder their developmental milestones, particularly in speech and language acquisition. However, due to children limited attention span, variable responsiveness, and difficulty cooperating with structured testing procedures often complicate the evaluation process, requiring specialized techniques and considerable expertise. The suitable test to conduct is by using tympanometry using 226 Hz probe tone is commonly employed as an excellent non-invasive test with 90% sensitivity and a 75% specificity used to assess middle ear function.(Edward Onusko, 2004). It measures the condition of the middle ear function in response to air pressure and provides information about middle ear conditions.

Despite its widespread use of tympanometry at 226 Hz has inherent limitations when applied to children. It is because the 226 Hz probe tone frequency is found to be less effective due to middle ear is frequency dependent properties. In other words, a single frequency is not fully captured middle ear condition. Due to the limitation of 226 Hz, high probe tone frequencies such as 678 Hz and 1000 Hz are recommended as it offer increased sensitivity to detect middle ear pathologies. By investigating these parameters, this study aims to evaluate the use of tympanometric parameters using 226 Hz, 678 Hz and 1000 Hz in Malay children age 1-4 years old.

According to the Cambridge Dictionary, children aged 1-4 years old which describes young children just learning to walk, usually between the ages of 1 and 3 years. The term sometimes extends to cover young children up to age 4, focusing on early developmental years before starting school.

1.2 Problem Statement

The assessment of middle ear function in children aged 1-4 years is critical for early detection of auditory issues that can affect speech and language development. The prevalence of conductive pathology in children was 51.62 cases reported per 100,000 patients in 2016.(Kennedy et al., 2024). Conductive hearing loss can affect hearing up to the moderate level of hearing loss in children, which can significantly impact speech and language development. Children with moderate hearing loss may struggle to understand speech, particularly in noisy environments, and may experience delays in language acquisition and articulation skills. Therefore, in a standard clinical setting the used of conventional tympanometry primarily utilizing a 226 Hz probe tone, has been the standard diagnostic tool employed to assessed middle ear function as an excellent non-invasive test with 90% sensitivity and 75% specificity.(Edward Onusko, 2004)

However, research suggests that utilizing higher probe frequencies, specifically 678 Hz and 1000 Hz, can enhance the sensitivity of tympanometric assessments by 100% and 94% and allow for a more comprehensive evaluation of middle ear health by capturing a broader spectrum of frequency ranges.(Terzi et al., 2015).

Therefore, the aims to analyse data for these frequencies and evaluate their diagnostic accuracy compared to conventional 226 Hz tympanometry. By addressing these gaps, this research seeks to improve early detection and intervention strategies for middle ear in children aged 1-4 years old, ultimately supporting their communication skills and overall developmental milestones.

According to previous study by Shahnaz and Davies (2006a) mentioned there is significant different between tympanometric parameters and ethnicity. As analysis done to compare between Malay and Caucasian toddlers showed Malay toddlers generally had lower mean tympanometric parameters compared to Caucasian toddlers.(Alaudin et al., 2010).(Palmu and Rahko, 2003). Besides, Lih et al. (2017) studied reported no significant differences between the two ethnic groups of tympanometric parameters in young Malay and Chinese adults Thus, my study focus on Malay children. The study will be conducted in Kelantan, focusing specifically on the Malay ethnic group, which constitutes a significant majority in the state. As of 2023, Kelantan's estimated population is approximately 1.857 million, with around 95% identifying as Malay Muslims. This demographic data implies that the Malay community in Kelantan comprises roughly 1.76 million individuals, making it a representative sample for examining issues relevant to this ethnic group. The study's focus on Malays is thus appropriate, given their prominence within Kelantan's population structure.(Thomas Brinkhoff, 2023).

1.3 Research Questions

1. What is the test–retest reliability of tympanometric parameters of multifrequency tympanometry?

3. What is the different mean of tympanometric parameters for 226 Hz,678 Hz and 1000 Hz in Malay children age 1-4 years old?

4. Is there any correlation between tympanometry parameters and age for Malay children age 1-4 years?

1.4 Objective

1.4.1. General:

To compare the multifrequency (226 Hz, 678 Hz and 1000 Hz) tympanometry parameters in Malay children age 1-4 years old.

1.4.2. Specific:

1. To determine test - retest reliability of multifrequency tympanometric parameters.

2. To determine and compare mean tympanometric parameters between 226 Hz, 678 Hz and 1000 Hz.

3. To determine the correlation between tympanometric parameters and age.

1.5 Hypothesis

1.5.1 Null Hypothesis:

1. There is no significant difference of the mean multifrequency tympanometry parameters for each 226 Hz,678Hz and 1000 Hz in children aged 1-4 years.

2. There is no correlation between multifrequency tympanometric parameters and aged for children aged 1-4.

1.5.2 Alternative Hypothesis:

1. There is a significant difference mean of multifrequency tympanometry parameters for each 226 Hz,678Hz and 1000 Hz in Malay children aged 1-4 years.

2. There is a correlation between multifrequency tympanometry parameters and age.

CHAPTER 2

LITERATURE REVIEW

2.1 Implementing early hearing screening

It is important for children aged 1-4 for hearing screenings to identify childhood hearing loss that may develop after the newborn period. According to Yamamah et al. (2012), finding showed in 80.7% of children with normal hearing were screened, and 27.5% showed the presence of middle ear issues. Another study done by Allison R. Mackey et al. (2024), showed that there are many cases of childhood hearing loss that are not congenital but develop later, highlighting the need for pre-school screenings to identify the hearing loss in children. Thus, it is essential for the early detection and management of hearing loss in children. Hearing screening in children includes a tympanometry test which is a diagnostic procedure that assesses the function of the middle ear by measuring the movement of the tympanic membrane (eardrum) in response to varying air pressure. The tympanometry test using 226 Hz probe tone is suitable for hearing screening in children as it has 90% sensitivity and 75% specificity.(Edward Onusko, 2004). This non-invasive test provides valuable information about middle ear health and is particularly useful in diagnosing conditions such as otitis media, tympanic membrane perforations, and Eustachian tube dysfunction. The results are recorded on a graph known as a tympanogram, which can indicate various middle ear pathologies.

2.2 Multifrequency Tympanometry

2.2.1 Significance of using Multifrequency Tympanometry

Multifrequency tympanometry (MFT) provides detailed insights into how the components of admittance include conductance (G), mass reactance, and stiffness reactance. It varies as a function of probe frequency. These variations can differ significantly between normal and pathological cases, offering critical diagnostic information. MFT is an advanced method of acoustic immittance measurement that provides values for resonance frequency (RF) of the middle ear in which the frequency of the total susceptance is zero.(Ozturk et al., 2010). Multifrequency tympanometry utilizes various probe tones, such as 226 Hz, 678 Hz, and 1000 Hz, to provide a comprehensive assessment of middle ear function, each revealing distinct tympanometry patterns.

2.2.2 Mass and Stiffness system in middle ear

The parameter of resonant frequency (RF) in the middle ear system represents a critical transition point between stiffness-dominated and mass-dominated acoustic behaviour. The interplay between mass and stiffness in the middle ear system represents a fundamental biomechanical mechanism governing its frequency-dependent transfer function. This dynamic relationship demonstrates inverse correlational properties as mass facilitates the transmission of low-frequency acoustic energy while attenuating high-frequency transmission, whereas stiffness facilitates high-frequency transmission while attenuating low-frequency acoustic energy. This antagonistic relationship creates the characteristic band-pass transfer function of the middle ear, with optimal efficiency (24-29 dB gain) observed at 1-2 kHz across human and feline models. The impedance at lower frequencies is predominantly mediated by elastic stiffness arising from the tympanic membrane, ossicular ligaments, and pneumatic properties of the middle ear cavity, while impedance at higher frequencies is primarily attributable to the inertial mass of the ossicular chain. These biomechanical principles elucidate various pathophysiological conditions: the acoustic reflex demonstrates frequency-specific stiffness-mediated attenuation below 2 kHz; otitis media presents with progressive hearing impairment corresponding to incremental changes in both stiffness and mass components; and otosclerosis manifests with characteristic low-frequency conductive hearing loss and the pathognomonic "Carhart's notch" resulting from stapedial fixation and consequent alterations in impedance mechanics.(Kim and Koo, 2015).

2.3 Multifrequency Tympanometry in Children

Multifrequency tympanometry employs different probe tones (226 Hz, 678 Hz, and 1000 Hz) to assess middle ear function, each providing distinct diagnostic insights. Multifrequency tympanometry has emerged as a highly promising technique for evaluating middle ear conditions, offering several advantages over conventional tympanometry performed at the standard frequency of 226 Hz. This advanced method is fast, straightforward, non-invasive, and objective, while demonstrating significantly greater sensitivity in detecting subtle and complex middle ear pathologies.(Ocak et al., 2023). The 226 Hz probe tone is the conventional standard, particularly effective for adults, as it typically produces a single peak tympanogram indicative of normal middle ear function. However, in children, especially those under 4 years old, this frequency can yield misleading results due to the unique anatomical and physiological characteristics of their ears, often leading to flat or double-peaked tympanograms that may suggest dysfunction when none exist.

2.3.1 Multifrequency Tympanometry in Children (226 Hz and 678 Hz)

The 226 Hz frequency is widely used due to its ease to interpretation and established norms, primarily focusing on stiffness dominated in the middle ear. However, it is not effective for identification common disorders but may not detect subtle pathologies or mass dominated issues as accurately as high frequency. In contrast, the 678 Hz probe tone is increasingly recognized for its ability to reveal subtle middle ear pathologies that 226 Hz may miss. It provides the most reliable results in this demographic due to its higher frequency aligning better with the resonance characteristics of pediatric ears, which typically fall between 300-400 Hz which are more reliable for evaluating the mass-dominated middle ear characteristics. Unlike the typical single-peaked tympanogram observed at 226 Hz, tympanograms at 678 Hz can display multiple peaks or more intricate shapes.(Young Joo et al., 2003). These complex patterns are analyzed to assess the condition of the middle ear. A double-peaked tympanogram at this higher frequency, such as in Multi-Frequency Tympanometry (MFT), often suggests that the middle ear is resonating at the probe frequency, providing valuable insight into the middle ear's functionality and potential pathologies. When tympanometry is measured at the resonance frequency, the impedance reaches its minimum due to negligible contribution of mass and stiffness dominated system. At this point, the middle ear system primarily reflects the effects of friction as the resonant frequency minimizes the resistive forces from other mechanical factors.

2.3.2 Multifrequency Tympanometry in Children in higher frequency (678 Hz and 1000 Hz)

Whereas the 1000 Hz probe tone is particularly advantageous for infants and young children. This frequency enhances sensitivity to middle ear effusions and other dysfunctions, often resulting in clearer single or double peak responses that facilitate accurate diagnosis and intervention. (de Resende et al., 2012; Polpeka Gerald, 2007)A single peak tympanogram, typically observed with the 226 Hz frequency, indicates normal middle ear function and optimal compliance of the tympanic membrane. In contrast, tympanometry reveals more complex tympanogram shapes particularly notched that are influenced by the direction of pressure change. When using high frequency stimuli 1000 Hz, conductance (G) measurement resulted in highest percentage of Type A tympanograms. When measuring other admittance components (B, B/G, and Y).(Young Joo et al., 2003). Additionally, no peak responses often indicate significant middle ear dysfunction or blockage, while other peak configurations can provide insights into specific conditions such as ossicular chain discontinuity or Eustachian tube dysfunction. The use of 678 Hz and 1000 Hz is essential in children because these frequencies enhance sensitivity to subtle middle ear issues that may not be captured by the conventional 226 Hz measurement, thereby facilitating earlier diagnosis and intervention for auditory problems.(Iacovou et al., 2013).

2.4 Early detection and Intervention

Early detection of hearing loss in children is essential for facilitating timely interventions that support optimal speech and language development. Hearing screening programs, implemented globally, aim to identify auditory impairments as early as possible. Research indicates that a significant percentage of children who pass initial screenings may still have undetected middle ear abnormalities that can lead to moderate hearing loss, underscoring the need for comprehensive screening protocols. (Yamamah et al., 2012).

Current methodologies for hearing assessment include both behavioral and objective tests, with tympanometry being a widely used objective measure to evaluate middle ear function. Traditional tympanometry typically employs a 226 Hz probe tone, which is effective for adults but has limitations in pediatric populations due to the unique anatomical characteristics of children's ears. To address this limitation, multifrequency tympanometry using higher frequencies such as 678 Hz and 1000 Hz has emerged as a more effective diagnostic tool. These frequencies enhance sensitivity to middle ear dysfunction and provide clearer assessments, thereby improving early detection rates.(Tsilivigkos et al., 2024).

The benefits of early intervention following the identification of hearing loss are well-documented. Studies have shown that children who receive appropriate auditory rehabilitation such as hearing aids or cochlear implants demonstrate significant improvements in speech and language outcomes compared to those diagnosed later.(Yoshinaga-Itano et al., 1998).Furthermore, timely interventions tailored to individual needs can mitigate the adverse effects of hearing loss on cognitive and social development. In conclusion, integrating advanced screening techniques like multifrequency tympanometry into routine pediatric assessments is essential for the early detection of hearing loss. By identifying auditory issues promptly and facilitating timely interventions, healthcare providers can significantly enhance developmental outcomes for children, ensuring they reach their full potential during critical early years of communication skill acquisition. Future research should continue to explore the efficacy of these screening methods and their impact on long-term developmental trajectories in children with hearing impairments.

2.5 Previous study about Multifrequency Tympanometry.

A study conducted by Liden et al. (1970) on tympanometry, a method used to assess middle ear function, identified two characteristics of tympanogram patterns when using different frequencies. When an 800 Hz pure tone was used, sharp, notched tympanograms were recorded from ears with hypermobile eardrums or atrophic scarring, while broad, undulating, peaked tympanograms were observed in cases of ossicular discontinuity or after stapedectomy, which are mass-related middle ear conditions. In contrast, when a 226 Hz pure tone was used, the tympanograms from the same ears always exhibited a single peaked pattern. This finding illustrates that high-frequency probe tones provide valuable insights into the mass-related characteristics of the middle ear, particularly the eardrum and ossicles. On the other hand, low-frequency probe tones offer information about the stiffness characteristics of the middle ear as well as the volume of air present medial to the probe tip.

Lai et al. (2008) conducted a study comparing multifrequency tympanometry (MFT) with conventional 226 Hz tympanometry in 80 adults with otitis media with effusion (OME). The study found that the average resonant frequency (RF) in healthy adults was 1007 Hz, whereas OME patients exhibited significantly lower RF values (400 Hz). MFT was able to detect persistent middle ear abnormalities even when conventional tympanometry results appeared normal. During recovery, RF values gradually increased, closely aligning with acoustic reflex recovery. The low RF values in OME patients indicate mass loading of the middle ear due to fluid accumulation. Moreover, the delayed normalization of RF, despite normal conventional tympanometry findings, suggests potential long-term tympano-ossicular pathologies, such as thickened tympanic membranes, residual fluid, or reduced middle ear volume. The strong correlation between RF and acoustic reflex findings highlights the potential of RF measurement as a valuable tool for monitoring OME recovery. Unlike conventional tympanometry, which primarily assesses stiffness-related components, MFT provides insights into both stiffness and mass-related characteristics of middle ear function.

2.6 Previous study about differences between races and gender.

An analysis done by Wahab et al. (2009) of tympanometric values of young Malay adults involved 96 young Malay adults (49 males, 47 females) from Universiti Kebangsaan Malaysia, aged 19-25, participated voluntarily. Both groups had a similar age distribution (mean age around 21 years), and screening included various tests to ensure participants had normal hearing and ear health. These included otoscopic exams, pure tone audiometry, acoustic reflex testing, and tympanometry. Out of 114 initially screened participants, only 154 ears (80 from males, 74 from females) met all inclusion criteria. Testing was conducted in a soundproof room using calibrated equipment. The tympanometric parameters Peak Ytm, Vea, and TW were analyzed. Vea was normally distributed, while Peak Ytm and TW were not. Statistical tests revealed no significant difference between ears, so data from both ears were combined for analysis. However, gender-based differences were found males had a significantly higher mean Vea (1.48 cm^3 vs. 1.12 cm^3) and Peak Ytm (0.81 mmhos vs. 0.63 mmhos) compared to females. These findings suggest the potential need for gender-specific tympanometric reference values.

Based on study by Kavruk and Öztürk (2024), the aim of this study is to examine the effects of age and gender on the middle ear with wideband tympanometry (WBT) in three different age groups consisting of young, middle-aged and older adults. This study was done on 95 adults with healthy middle ears were divided into three age groups: young (20-39), middle-aged (41-60), and older adults (65-82). WBT measurements captured energy absorbance at peak and ambient pressures. The findings showed that older adults had higher energy absorbance at mid-frequencies compared to younger adults. Middle ear showed no significant differences compared to younger or older adults. Older adults also had a lower resonance frequency (RF), meaning their ear structures vibrated at a lower pitch. Whereas the gender differences included the men generally had higher absorbance at low frequencies and lower absorbance at high frequencies compared to women. Men also had slightly lower RF, particularly in the middle-aged group.

Lih et al. (2017) conducted a study on the influence of ethnicity and gender on tympanometric parameters. The study included 31 young Malay adults and 41 young Chinese adults with normal middle ear function. The findings indicated no statistically significant differences in tympanometric parameters between the Malay and Chinese participants. However, significant gender-related differences were observed, with male participants exhibiting higher SA and ECV values compared to females.

In contrast a study by Wei De (2020) involving Singaporean adults reported significant differences in tympanometric parameters between Chinese and non-Chinese individuals (including Malays, Indians, and other ethnic groups). These results are consistent with those of Shahnaz and Davies (2006b), found that ethnicity significantly influenced tympanometric measures at 226 Hz. The study has showed that the Chinese participants demonstrated lower SA, wider TW, more positive TPP, smaller ECV, and higher resonant frequency (RF) compared to Caucasian.

CHAPTER 3

METHODOLOGY

3.1 Research design

This study used a cross-sectional design to analyse tympanometry parameters for each 226 Hz, 678 Hz and 1000 Hz in healthy Malay toddlers. Before collecting any data, ethical approval was obtained, and informed consent was gathered from the guardians of all participants.

3.2 Study area

The study was conducted in many places (eg: Audiology Clinic, daycare and kindergarten).

3.3 Study population

The study population for this research were focus on Malay children aged between 1 to 4 years old (up to 4 years and 11 months) living in Kelantan, Malaysia. This demographic is selected due to the predominance of Malay ethnicity in the region, where Kelantanese Malays make up approximately 94% of the state's population. The participants were recruited from local daycare and kindergarten in Kelantan to ensure a representative sample of the target age group. The inclusion criteria were focused on children with normal hearing to evaluate tympanometric parameters which are essential for distinguishing normal middle ear function from conditions linked to conductive pathology.

3.4 Subject criteria

3.4.1 Inclusion criteria

The group requires healthy participants aged 1-4 years with normal middle ear function with pass screening ipsilateral acoustic reflex testing at 1 kHz and pass DPOAE at 2-5 kHz. Children with at least one ear meets the criteria also were accepted.

3.1.1 Exclusion criteria

Children with no cooperation, children with structural abnormalities (Microtia and Atresia), unable to get seal probe and non-Malay ethnicity.

3.5 Sample size estimation

The sample size was calculated using the PS Power and Sample Size Calculation software (version 3.1.2) developed by D. Dupont and Plummer in 2009. The calculation was based on the study by Özgül Ünlüer et al. (2014), using an alpha value of 0.05, a study power of 0.8, a mean difference of 0.26, and a standard deviation of 0.5. The minimum required sample size was determined to be 31 participants. Accounting for a 10% dropout rate, the final sample size was adjusted to 36. The study was stratified to ensure equal representation across four age groups, with nine participants allocated to each group. The age groups are divided as follows: Group 1 (12–23 months), Group 2 (24–35 months), Group 3 (36–47 months), and Group 4 (48–59 months).

3.6 Sampling method and subject recruitment

This study recruited a group of Malay toddlers aged between 1 and 4 years old who volunteered and fulfilled the inclusion criteria, using a convenience sampling method among participants from various places (e.g., Audiology Clinic, daycare, and kindergarten).

All participants underwent hearing screening to determine their eligibility. The hearing screening included otoscopy examination, acoustic reflex (ipsilateral left and right), and otoacoustic emission (OAE). These tests were carried out according to standard procedures and took approximately 15–30 minutes to complete.

3.7 Study Tools and Protocols

3.7.1 Study Tools

This study employed clinical instruments routinely used in audiological practice. The equipment included an otoscope, an immittance audiometer, and a distortion product otoacoustic emission (DPOAE) device. The specific models of the instruments are presented in the attached figures.

Figure 3.1 Otoscope (welch Allyn)

Figure 3.2 Tympanometry (GSI Tympstar Pro)

Figure 3.3 Otoacoustic emission (Interacoustics)

3.7.2 Study Protocol

All participants underwent a comprehensive hearing screening to determine their eligibility, which included otoscopic examination, distortion product otoacoustic emissions (DPOAE), and acoustic reflex testing at 1000 Hz. The screening aimed to evaluate the middle ear and cochlear function. Participants who passed the hearing screening proceeded to the main study, which involved multifrequency tympanometry using 226 Hz, 678 Hz, and 1000 Hz probe tones. Each frequency was measured twice per ear to ensure reliability. A video posted on YouTube for parents' reference are attached in Figure 3.7.

Table 3.1 Type of stimulus and recording parameters for the acoustic reflex testing

	Parameters	**DPOAE**
Stimulus	**Type**	Pure tone
	Intensity	55-75 dBSPL
	Frequencies tested	2kHz-5kHz
Recording	**Transducer**	Probe

Table 3.2 Type of stimulus and recording parameters for the acoustic reflex testing

	Parameters	**Acoustic reflex**
Stimulus	**Type**	Steady tone
	Intensity	100 dBSPL
	Frequencies tested	1kHz
Recording	**Transducer**	Probe

Table 3.3 Type of stimulus and recording parameters for the tympanometry testing

	Parameters	**Tympanometry**
Stimulus	**Type**	Pure tone
	Intensity	85 dBSPL
Recording	**Transducer**	Probe
	Probe tone frequency	226 Hz, 678 Hz, 1000 Hz
	Pressure sweep speed	600/200 daPa/second

	Parameters measured	• Ear canal volume (ECV) • Static admittance (SA) • Tympanometric peak pressure (TPP) • Tympanometric width (TW)

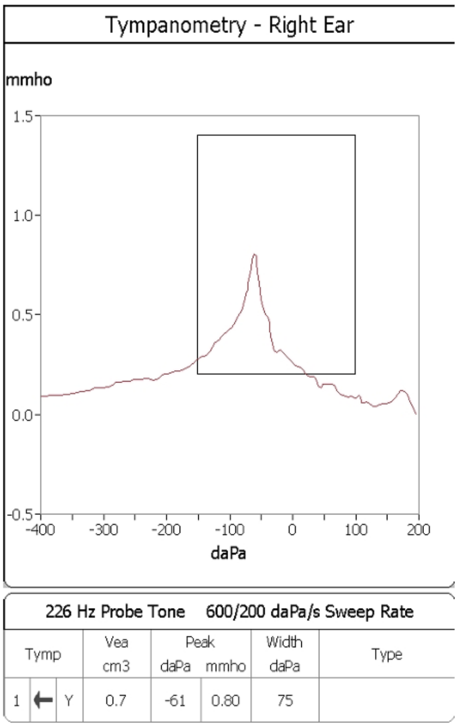

Figure 3.4 Tympanometry using 226 Hz probe tone

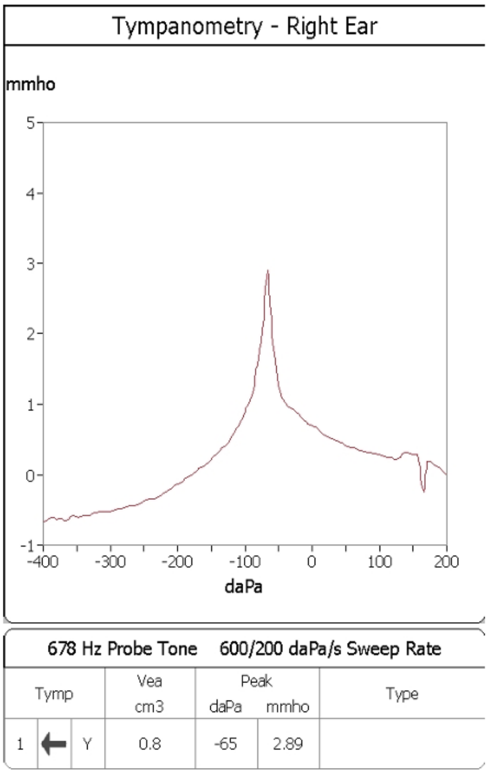

Figure 3.5 Tympanometry using 678 Hz probe tone

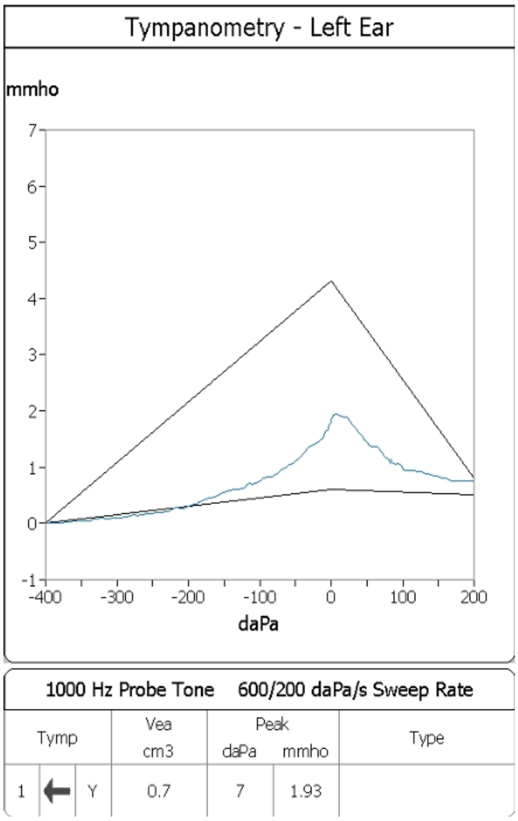

Figure 3.6 Tympanometry using 1000 Hz probe tone

Figure 3.7 Study procedure's video on https://youtu.be/YHELKP8KwvQ

3.8 Methodology

All participants underwent a comprehensive hearing screening to determine their eligibility for inclusion in the study. The screening protocol comprised several procedures aimed at evaluating middle ear function, as detailed below:

The screening began with an otoscopic examination to visually assess the external auditory canal and tympanic membrane (TM) for any abnormalities, such as cerumen impaction, inflammation, perforation, or the presence of middle ear effusion. This was followed by otoacoustic emissions (OAE) testing using distortion product otoacoustic emissions (DPOAE). The OAE assessment was used to evaluate cochlear function and, indirectly, to infer middle ear status. DPOAE responses were elicited using two pure-tone stimuli introduced into the external auditory canal, with emissions measured at frequencies ranging from 2 kHz to 5 kHz.

Subsequently, acoustic reflex testing at 1000 Hz presented at 100 dB ipsilateral was conducted to aid in identifying any potential conductive pathology. According to British Society of Audiology (2025) recommended procedure ipsilateral acoustic reflex testing has advantages compared to contralateral testing. The advantages including it is highly sensitive to middle ear disorders, not affected by disorder in opposite ear and it also can be performed when behavioral cooperation is limited making it reliable indicator for detecting middle ear problem. Participants who passed all components of the screening proceeded to a multifrequency tympanometry assessment. All participants underwent for main study multifrequency tympanometry using 226 Hz, 678 Hz, and 1000 Hz probe tones.

Parental informed consent was obtained from all participants, ensuring confidentiality and ethical handling of data. All collected information was anonymized using unique identification codes and stored securely physical documents in locked storage and electronic data protected with password encryption. Access to data was limited to authorized research personnel.

Upon study completion, data and documents were disposed of securely through shredding and digital deletion. Individual test results were anonymized in all reports.

This study was conducted after obtaining ethical approval (JEPeM Code: USM/JEPeM/KK/24121130) from the Jawatankuasa Etika Penyelidikan Manusia USM (JEPeM).

Study flowchart

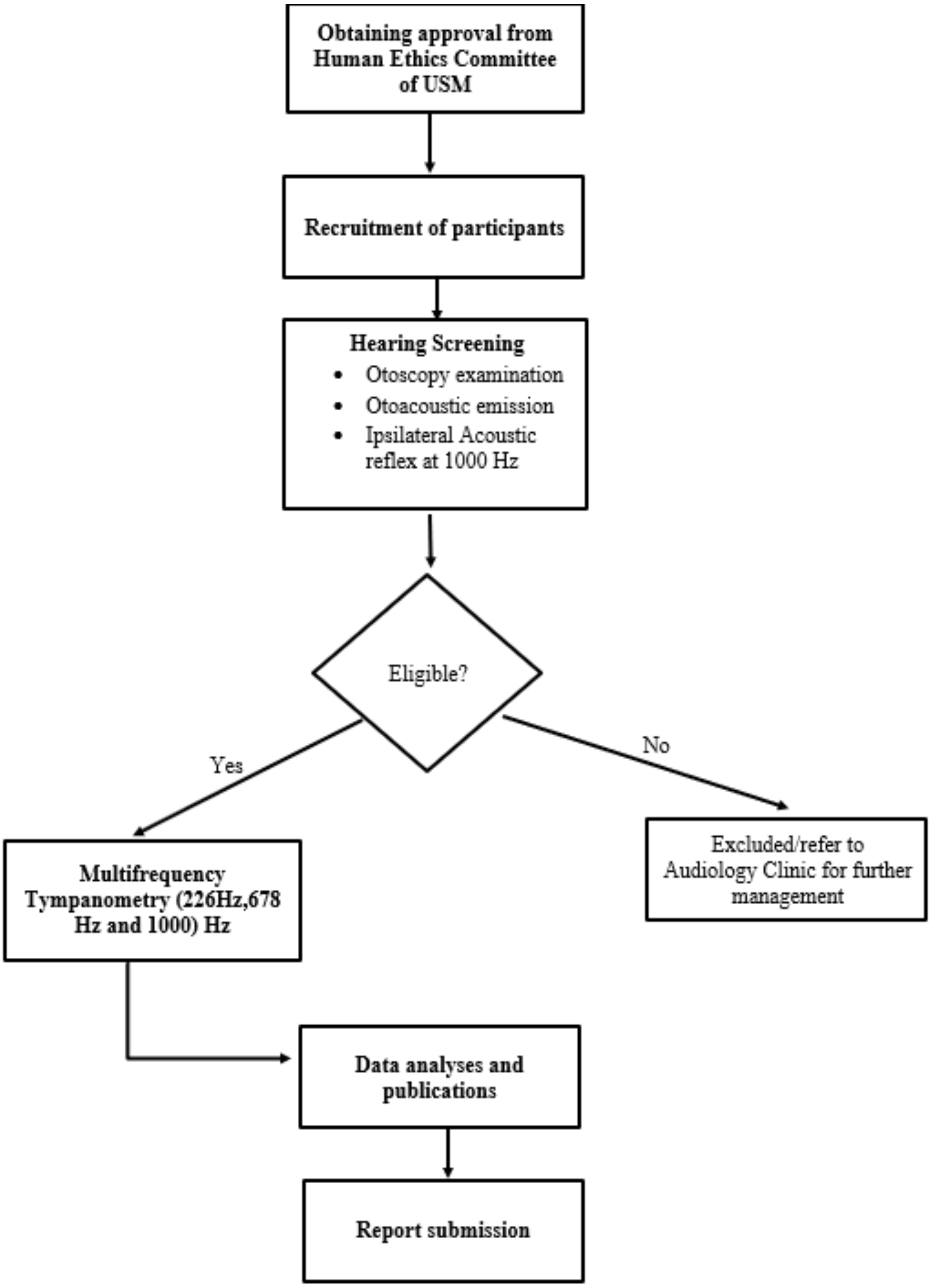

Figure 3.7 Study flowchart