Investigation of the benefits of New Zealand prescribed hearing aids for bilingual Mandarin and English speakers in speech-in-noise tests

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ABSTRACT

Background: For Chinese people living in New Zealand, Mandarin is usually their first language, while English is the language mainly used in their surrounding environment. Hearing loss is a common issue that impacts people's life. Previous studies have demonstrated that people with hearing loss can hear their first language better than their second language in noisy environments. Additionally, studies have shown the benefits of hearing aids in helping people with hearing loss hear speech in noisy situations.

Aims: This research aims to investigate the benefits of New Zealand prescribed hearing aids for individuals who speak Mandarin as their first language and English as their second language.

Method: Participants who were over 18 years old, spoke Mandarin as their first language and English as their second language, and wore New Zealand prescribed hearing aids were recruited to participate in the research tests. The research tests involved Mandarin and English speech in noise tests. An adaptive testing procedure was employed to determine the 50% correct thresholds.

Results: The results indicated New Zealand prescribed hearing aids provided similar benefits to bilingual individuals who spoke Mandarin as their first language and English as their second language when they came to hear Mandarin speech in noise, in comparison to hearing English speech in noise.

Conclusion: This finding suggests that New Zealand prescribed hearing aids effectively support bilingual speakers (with Mandarin as their first language and English as their second language) in improving their ability to hear speech in noise. This finding has important implications for future clinical practice.

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CHAPTER 1. INTRODUCTION

1.1 What calls for this research?

Hearing loss can impact a person's understanding of speech and add extra difficulties in hearing speech in noisy environments. It can further lead to social isolation. Hearing loss is a common issue primarily caused by various factors, including aging, noise exposure, ototoxicity, genetic mutations, and chronic conditions (Cunningham & Tucci, 2017). The New Zealand Hearing Industry Association reported in 2018 that approximately one in six New Zealanders experienced hearing loss, and this number was expected to continue rising (Anovum, 2018). New Zealand is a country with a rich diversity of ethnicities, and the Asian population, especially the Chinese, constitutes a significant ethnic group within the New Zealand population (Stats_NZ, 2019). Therefore, the issue of hearing loss among Chinese community poses a significant challenge for the government and other stakeholders in the country.

One cannot ignore the language factors when addressing the hearing loss among the Chinese community. While English is the primary language spoken by most New Zealanders on a daily basis, many Chinese individuals typically consider Mandarin as their first language, with English being their second language used for communication with individuals outside of their community. Mandarin and English are typical examples of tonal and nontonal languages, respectively. Their different language properties can lead to varied hearing outcomes when individuals with hearing aids listen to them. Currently, there is a common belief that people tend to hear their first language better than their second language in noisy environments (Sebastián-Gallés, 2005). Studies have also proved the benefits of hearing aids in supporting people in hearing speech in noisy environments (Souza, 2016). However, there has been no study targeting the Chinese community in New Zealand regarding the potential benefits they may derive from the hearing aids prescribed here.

Thus, this research developed Mandarin speech and English speech in noise tests to determine the extent to which New Zealand-prescribed hearing aids benefit bilingual speakers (Mandarin as their first language and English as their second language) in hearing speech amidst background noise.

1.2 How is this thesis structured?

This thesis will begin by reviewing the relevant literature on language, speech perception, and hearing aids technologies. It will then outline the research aims and define the associated hypotheses. Following the research design, it will explore the methods employed, including the protocol, equipment configuration and testing procedures. Once the research results are available, it will perform quantitative analysis of the data and discuss the findings. Most importantly, this thesis will highlight the implications of the findings for clinical practices.

CHAPTER 2. LITERATURE REVIEW

2.1 Language and speech

2.1.1 Introduction to language and speech

Language is a distinct form of human communication; it serves as a mean of connecting various social groups (Feldman, 2019). Language utilizes units such as words and sentences within a structured system to convey information (Feldman, 2019). A language comprises components or subsystems that interact with one another, including the lexicon (vocabulary), syntax (grammar), semantics (meanings), phonology (the system of speech sounds), and pragmatics (social aspects of language, such as context and speaker) (Feldman, 2019). Speech, as a general output of the language system, represents a unique human ability to communicate with others (Denes & Pinson, 1993). It involves intricate movements of respiratory, laryngeal, velopharyngeal, and oral structures (Feldman, 2019) and encompasses subsystems such as voice and resonance, articulation (speech sounds), and fluency (Feldman, 2019). While humans have various means of communication, such as sign language, Morse code, or writing, speech remains the most efficient and convenient method that enables the expression and exchange of ideas (Denes & Pinson, 1993). The sounds of speech serve as a distinct vehicle for communication, distinguishing it from other modes of communication.

2.1.2 The speech chain

Acoustically and linguistically, when two people are orally communicating with each other, several processes occur. The speaker, who intends to convey information to others, needs to organize his/her ideas and transform them into linguistic forms. This involves selecting appropriate words or phrases and following the grammatical rules of the language. This process is generated by brain activities, and send impulses are then sent along motor nerves to activate the vocal organs and produce sound waves (Denes & Pinson, 1993).

The sound waves produced by the speaker travel to the listener's ear and trigger the listener's hearing mechanism. The acoustic signals are then conveyed along the acoustic nerve pathway to the brain. The brain decodes and processes these input signals into meaningful linguistic information (Denes & Pinson, 1993). This entire process of speech communication is referred to as the "speech chain" (Figure 1). The speech chain encompasses information at the linguistic level, physiological level, and physical level (Denes & Pinson, 1993). The linguistic level involves the speaker selecting and choosing appropriate words and sentences to transmit a message. Following this level, the physiological level involves neural and muscular activities. Finally, the physical level aims to generate and transmit the sound waves. When the sound waves reach the listener's ear, the process is reversed, moving from the physical level to the physiological level and then to the linguistic level (Denes & Pinson, 1993). In this way, the entire speech chain is completed (Figure 1).

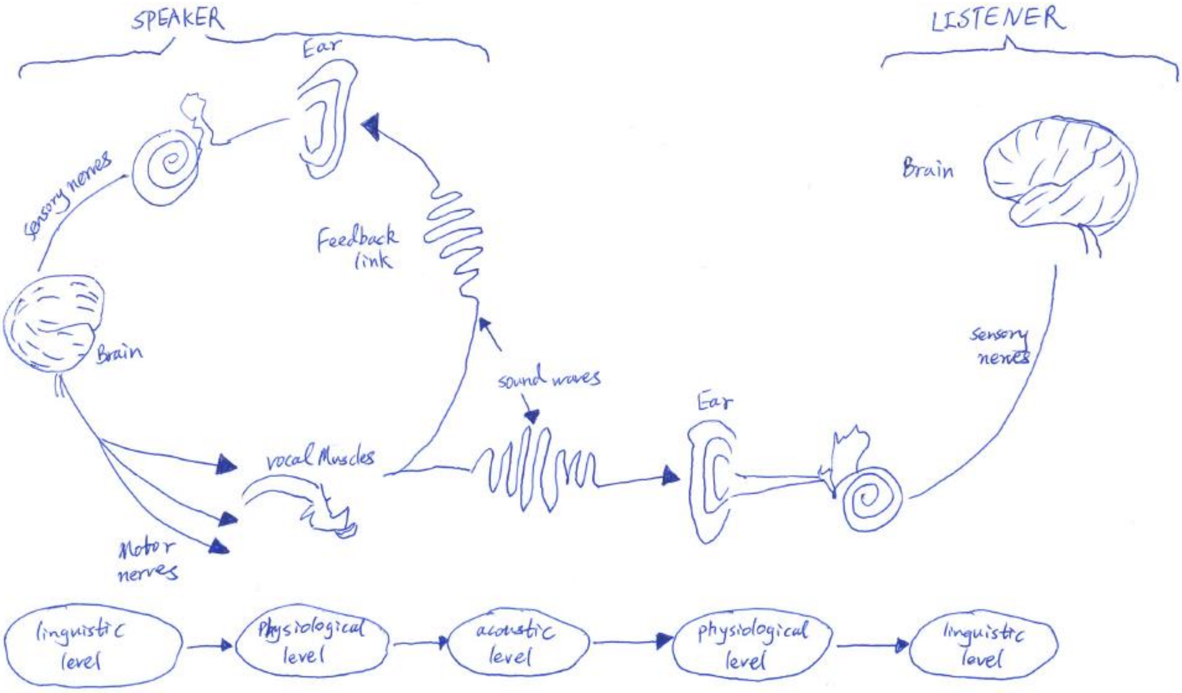

Figure 1: The speech chain: the different forms of a spoken message in its progress from the brain of the speaker to the brain of the listener.

(Retrieved from ‘*The speech chain*’ by Denes & Pinson, 1993, © Columbia University)

2.2 Speech perception

2.2.1 Introduction to speech perception

Speech perception is the human ability to hear and comprehend the meaning of acoustic representations of language (McRoberts, 2008). During the language acquisition process, one should be able to perceive the stages of language structure within speech signals, starting from basic units (phonemes) to meaningful linguistic structures like words or sentences, and then progressing to higher-level units composed of the units at the next lower level and constructed according to specific language rules, such as grammars (McRoberts, 2008). The ability of speech perception plays a fundamental role in language acquisition (McRoberts, 2008).

Speech perception involves neural, computational, and cognitive operations that transform auditory signals into representations that correspond to the listener's stored lexicon (Poeppel & Monahan, 2015). The goal of speech perception is to understand the speaker's message, which necessitates the listener's ability to recognize and differentiate the words within the speech (Mitterer & Cutler, 2006). The listener's linguistic knowledge forms the foundation for processing speech signals.

2.2.2 Human auditory processing

The human auditory system enables us to hear and understand sounds (Petersen, MacDonald, & Josefine Munch Sørensen, 2022). It consists of two main parts: the peripheral structure and the brain regions (Petersen et al., 2022). The peripheral structure includes the outer, middle, and inner ear (Figure 2), while the brain regions encompass the cochlear nuclei, superior olivary nuclei, lateral lemniscus, inferior colliculus, medial geniculate nuclei, and auditory cortex (Petersen et al., 2022).

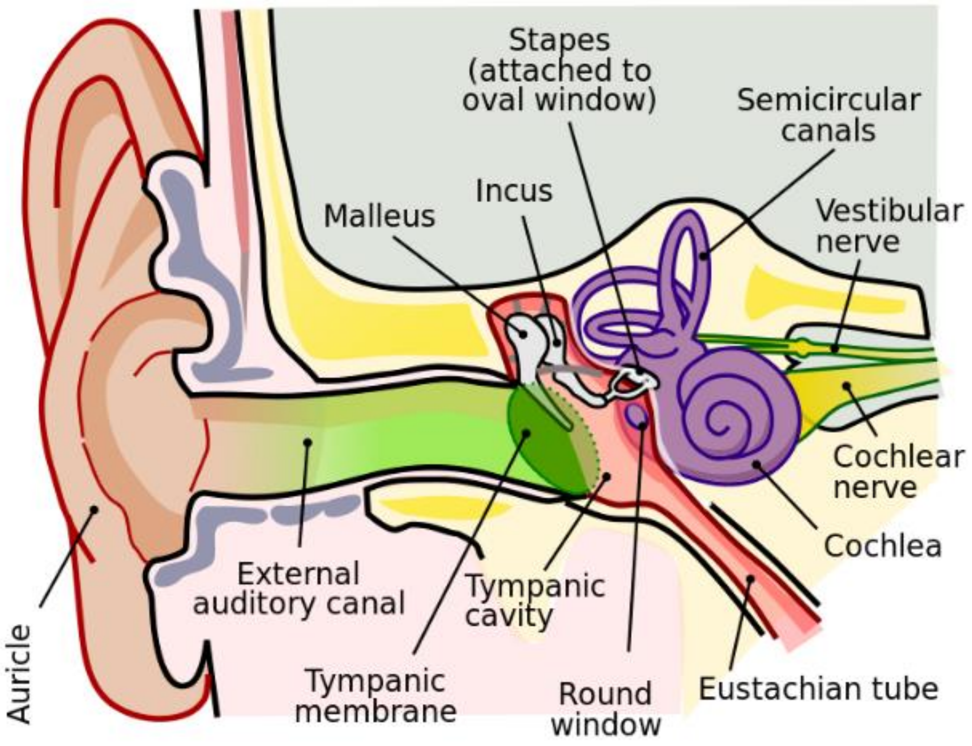

Figure 2: Anatomy of the ear

(Retrieved from "*Anatomy of the Human Ear"*. (2021, 4 Aug). Wikipedia. https://en.m.wikipedia.org/wiki/File:Anatomy_of_the_Human_Ear.svg)

Sounds are generated by sources of mechanical vibrations, producing energy waves. These energy waves travel from the outer ear, contact the eardrum, vibrate the three small bones in the middle ear, and reach the cochlea in the inner ear (Figure 2). Within the cochlea, the auditory hair cells convert the mechanical energy of sound waves into electrical energy (Petersen et al., 2022). The location within the cochlea determines the response to different sound frequencies. Generally, the base of the cochlea responds to high frequencies, while the apex of the cochlea responds to low frequencies. The arrangement of hair cells within the cochlea, which respond to specific ranges of frequencies, is referred to as the tonotopic gradient (Petersen et al., 2022). Sounds are represented in a tonotopic manner and are analysed based on their different frequencies in the stimulus. The process of separating sounds based on frequencies is known as frequency selectivity. Speech signals are decomposed into sinusoidal frequency components, which are represented in different populations of neurons. The activities of these neurons tune the speech signals into different frequencies (Young, 2008). To model frequency selectivity, the peripheral auditory system can be considered as a bank of bandpass filters tuned to different frequencies, also known as auditory filters (Young, 2008). When sound waves pass through the cochlea, they cause vibrations in the basilar membrane. Each point on the basilar membrane corresponds to a filter with a different central frequency (Moore, 2008).

When sounds are transmitted from the peripheral auditory system to the central auditory system, the sound signals first pass through the auditory nerve and ascend through the auditory pathways. The auditory nerve carries the sound information to the auditory nuclei and eventually to the auditory cortex located in the temporal lobe of the cerebral cortex, where perception occurs (Petersen et al., 2022). At each level of the auditory system, there are a significant number of neurons with crossing fibres (Petersen et al., 2022). The electrical activity generated within the organ of Corti or auditory nerve can be measured using electrodes (Abbas & Miller, 1998). These captured responses are potentials that are generated when our auditory system responds to sounds (Abbas & Miller, 1998).

2.2.3 Dual-stream models

A dual processing stream for speech processing was initially proposed by Wernicke and has been further developed in its current form (Hickok & Poeppel, 2007). Spectro-temporal analysis is involved in the early stage of cortical speech processing and occurs in the bilateral auditory cortices (Hickok & Poeppel, 2007). This system includes the middle to posterior portions of the superior temporal sulcus (STS) bilaterally, which are responsible for phonological-level processing and representation (Hickok & Poeppel, 2007).

The spectro-temporal analysis is then divided into two dual streams: the ventral stream and the dorsal stream (Hickok & Poeppel, 2007). The ventral stream processes speech signals for comprehension, such as speech recognition and perception. It involves structures in the superior and middle portions of the temporal lobe (Hickok & Poeppel, 2007). The ventral stream maps acoustic sounds to meaning. This mapping process potentially involves conceptual and semantic representations, including distinctive features, phonemes, syllabic structures, words, grammatical structures, and semantic information. The function of the dorsal stream is less agreed upon, but it is generally believed to be responsible for mapping sound to action. It is involved in transmitting acoustic speech signals into articulatory representations in the frontal lobe, playing a fundamental role in speech development and production (Hickok & Poeppel, 2007).

2.3 Acoustic cues of speech perception

2.3.1 Phenomes

Speech perception involves the process of mapping acoustic speech signals to linguistic representations, such as phonemes, diphones, syllables, or words (L. L. Holt & Lotto, 2010). Phonemes are the smallest units of speech (McRoberts, 2008). They serve as the fundamental building blocks of meaningful language units, including morphemes (core units of meaning in language), words, phrases, and sentences. At the most basic level, speech consists of various combinations of phonemes (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). Many phonemes are encoded to allow a single acoustic cue to carry information (Liberman et al., 1967). In other words, speech is an encoding of phonemes (Liberman et al., 1967).

In real speech, it is challenging to identify individual phonemes in the speech stream due to the continuous nature of speech signals and the phenomenon of coarticulation. Coarticulation refers to the changes in speech articulation that occur in association with neighbouring speech segments, whether phonemes or visemes (Aleksic, Potamianos, & Katsaggelos, 2009). The effects of coarticulation introduce variability in the physical realization of phonemes, making it difficult to segment and identify them (Eimas, 1997). In speech, no signal is solely influenced by a single phonological unit; rather, it is a result of the combined effects of various phonological units (Mitterer & Cutler, 2006). As a result, speech signals lack invariant cues for lexical segmentation.

2.3.2 Vowels and consonants

Phonetically, speech production and perception involve distinguishing between two classes of phonemes: consonants and vowels (Xu, Gandour, & Francis, 2006). Generally, people differentiate between vowels and consonants based on how the sounds are produced. Vowels are produced with a relatively open vocal tract, allowing air and sound to move more freely through the vocal tract (McRoberts, 2008). On the other hand, consonants are produced with constriction or obstruction in the location and movement of the vocal tract.

As mentioned earlier, phoneme coarticulation frequently occurs, meaning that vowels and consonants are not produced independently but are influenced by the sounds around them (Samuel, 2011). Coarticulation is a significant source of acoustic-phonetic variation. For steady-state vowels, there are no challenges of invariance between the acoustic signal and perception because the perception of steady-state vowels primarily relies on the frequency position of the formants. However, in normal speech, vowels are often not steady-state due to the articulation between consonants and the rapid speech rate (Liberman et al., 1967). In these conditions, vowels can be influenced by preceding consonants and can, in turn, influence following consonants.

2.3.3 Parsing the speech signal into syllables

Apart from phonemes, another fundamental representation of speech access that is frequently proposed and studied is syllables. Syllables serve as the universal units of speech perception.

As a phonological unit, a syllable consists of two components: onset and rime (Treiman, 1989). The onset refers to the initial consonant or consonant cluster of a syllable, which is not obligatory in English (Treiman, 1989). The rime of a syllable is the vowel or consonant that follows the onset (Treiman, 1989). Different languages may exhibit varying similarities in the way they parse the speech signal into syllables. For instance, while the sequence /*ki*/ is not considered as two separate syllables (/*k*/ and /*i*/) in any language, but rather as one syllable. All languages have syllables, even though they do not always parse specific sounds into the same syllabic structure (Sebastián-Gallés, 2005). For example, a French speaker would naturally parse the sequence /*lemən*/ into two syllables (/*le*/ and /*mən*/), whereas an English speaker would parse it as /*lem*/ and /*ən*/ or /*lem*/ and /*mən*/ (Sebastián-Gallés, 2005). Although different languages may parse speech sounds into different syllables, syllables are universal units of speech that are examined by various studies exploring speech perception across languages.

2.3.4 Categorical perception

Due to the variable and continuous properties of speech signals, several factors can make speech perception challenging for listeners. For instance, different speakers can produce speech sounds with varying acoustic properties, even when producing the same phoneme. This variation arises due to differences in the size and shape of their vocal tracts, resulting in different articulations of the same speech sound. The rate of speech can also impact the realization of phonemes. Typically, a speaker produces around 10-15 vowels or consonants per second (L. Holt, 2009). If the speaker speaks at a higher rate, their articulatory gestures, such as the placement of the tongue tip on the alveolar ridge to produce a /*t*/ sound, will differ from those produced at a lower speaking rate. As a result, the acoustic signals reaching the listeners' ears will be affected. Additionally, coarticulation with the surrounding sounds, room reverberation, emotional prosody of speech, and other factors can influence the acoustics of speech.

Despite the numerous variables that affect acoustic signals, a significant challenge in speech perception is understanding the intended meaning of the speaker. Research suggests that listeners cope with acoustic variabilities by perceiving speech in a context-dependent manner and categorizing speech sounds. This process allows listeners to focus on phonemes as belonging to specific sound categories and disregard irrelevant acoustic variations (McRoberts, 2008), which is known as "categorical perception." Categorical perception is a fundamental principle of speech processing (Harnad, 1987), where humans rely on decoding variable speech signals into qualitatively discrete regions. Typically, two sounds drawn from the same region are perceived as "the same," while two sounds drawn from different discrete regions are perceived as "different" (Möttönen & Watkins, 2009). For example, when a listener is exposed to an artificially generated gradual series of sounds from /*ba*/ to /*pa*/, they are more likely to perceive an abrupt shift between the two sounds rather than a gradual shift that exists acoustically because the change occurs from one category to another (McRoberts, 2008; Samuel, 2011).

2.3.5 Categorical perception of different languages

Categorical perception can be language specific. Sounds that are categorized as part of one category in one language may not be categorized the same way in another language. For example, in a cross-language study of initial stop consonants conducted by Lisker & Abramson (1964), a key phonetic correlate of voice contrasts was identified: voice onset time (VOT). VOT refers to the duration between the release of articulatory occlusion (e.g., the opening of the lips) and the onset of voicing (Diehl, Lotto, & Holt, 2004). Regarding the perception of VOT in different languages, studies on English, Spanish, and Thai found clear evidence of categorical perception among native speakers of these languages (Lisker &

Abramson, 1970). However, the locations of the phoneme boundaries differed among the three language groups. These findings suggest that the emergence of categorical perception of VOT is influenced by the listeners' language experience, and they tend to be more sensitive to phonetic differences that are functionally relevant in their own language (Diehl et al., 2004). Furthermore, these findings imply that categorical perceptions may differ between languages.

2.4 Cross language speech perception

2.4.1 Introduction to cross language speech perception

Speech perception enables humans to parse the continuous stream of speech into distinct units, such as sentences, phrases, or words, which are constructed from phonemes. Phoneme inventories vary across different languages. Cross-language speech perception is a field of study that examines how listeners perceive languages differently from their own and the resulting perceptual differences between their native language and the second language (Sebastián-Gallés, 2005). Languages can differ from each other in various ways. For instance, many languages do not have words starting with three consonants, like the English word "string" (Sebastián-Gallés, 2005). When individuals hear a foreign language, they may experience speech "illusions," such as phonemic deafness (inability to perceive differences between certain sounds), mirage (perceiving acoustic information that is not present), and mutation (perceiving one sound as another) (Sebastián-Gallés, 2005). The Mismatch Negativity (MMN) response is a source of evidence for cross-language perception. MMN refers to the electrophysiological response in the brain when a deviant stimulus (different acoustic signals) interrupts a standard stimulus (identical signals) (Sebastián-Gallés, 2005). When listeners perceive non-native contrasts, they often exhibit reduced MMN responses (Näätänen et al., 1997). For example, Näätänen et al. (1997) investigated how Finnish speakers perceive Finnish vowels that exist only in Estonian but not in Finnish. They found that Finnish speakers had difficulty perceiving these vowels and demonstrated reduced MMN responses. This may be because Finnish speakers lack a phonetic category for that particular vowel. This finding highlighted larger MMN responses for cross-language phonemic category differences compared to within-language categories. Another study by McAllister et al. (2002) examined native Spanish and English speakers fluent in Swedish. Typically, neither Spanish nor English speakers use vowel durations as a primary cue for vowel contrasts, unlike Swedish speakers. This finding suggests that lexical differences between the first language and the second language can result in differential processing of sounds in the two languages (McAllister et al., 2002).

2.4.2 Speech perception of the first and second language

When listening to their first and second languages, listeners may experience differences in their speech recognition, especially in noisy conditions. The term "first language" refers to the language acquired by speakers from birth to around 7 or 8 years old as a native language, while "second language" refers to a language learned later in life and is considered non-native (Madisha, 2018). Research has shown that non-native speakers and native speakers can discriminate English words equally well in quiet environments (Guan, Cao, & Liu, 2021; Jin & Liu, 2012). However, when background noise is present, native speakers outperform non-native speakers (Gat & Keith, 1978; McCreery & Stelmachowicz, 2011). When listening to a non-native language, both children and adults with normal hearing exhibit good to excellent speech recognition (with accuracy ranging from 80% to 100%). However, as the level of background noise increases, the decline in speech recognition for non-native languages is greater compared to that for the native language (Nakamura & Gordon-Salant, 2011).

Many factors can influence an individual's speech recognition of their non-native language, including the age of non-native language acquisition, amount of language exposure, proficiency in the non-native language, and the semantic context (Rimikis, Smiljanic, & Calandruccio, 2013; Zhang, Xie, Li, Chatterjee, & Ding, 2014). Evidence suggests that when bilingual speakers speak or listen to their second language, their brains also activate processing related to their first language, which is referred to as parallel processing (Marian & Spivey, 2003). Sometimes, the perception of a non-native language is influenced by the phonotactic constraints of the first language. In other words, second language listeners may filter auditory input through the phonological rules of their first language when listening to non-native sounds (Freeman, Blumenfeld, Carlson, & Marian, 2022). For instance, Spanish-English bilinguals processing their second language, such as the English word 'strict,' may initially perceive it through the filter of their first language, Spanish. Consequently, they might access 'strict' with an 'e' onset as 'estrict' (Freeman et al., 2022). This is likely because the Spanish language requires a vowel, particularly /*e*/, at the beginning of all /s/ consonant cluster (s+c) words, while English allows the syllable structure of s+c. As bilingual individuals are exposed more to their second language, they become less perceptually influenced or repaired by the phonotactic constraints of their first language during second language processing (Carlson, Goldrick, Blasingame, & Fink, 2016). Perceptual repair refers to a situation where a sound presented does not conform to the individual's first language system, and they perceptually repair the sound to match the expectations of their first language (Freeman et al., 2022).

2.4.3 Perceptual Assimilation Model and Speech Learning Model

The native language plays a crucial role in influencing how we discriminate non-native sounds and perceive speech sounds (Millet, Chitoran, & Dunbar, 2022). Various models have been proposed to explain the characteristics of cross-language speech perception. One such model is the Perceptual Assimilation Model (PAM), which suggests that the structure of a listener's first language is significant in perceiving the second language. The PAM investigates how the native language influences speech perception and proposes that non-native speech perception is guided by the listener's assimilation to their native phoneme categories (Millet et al., 2022). For example, when English-speaking listeners encounter two sounds that do not belong to their native language, they predict the non-native contrast between the two sounds (Sebastián-Gallés, 2005) and map them into different native categories. Consequently, even in situations where one sound falls within the assimilated native category while the other does not, native listeners can still discriminate between them (Millet et al., 2022).

The Speech Learning Model (SLM) is another model that focuses on the acquisition of second language segments, particularly during the early stages of language learning (Sebastián-Gallés, 2005). According to the SLM, the greater the perceived phonetic distance between the second language and the similar sound in the first language is, the easier the phonetic difference between the sounds will be detected (Noske, 2011). Additionally, the SLM suggests that the ability to learn speech remains intact regardless of age (Flege, Schirru, & MacKay, 2003). In a study by Tremblay et al. (1997), native English speakers were trained to discriminate a speech sound (a prevoiced labial stop) that was not phonemically used in English. After the training, participants were asked to identify a prevoiced alveolar stop. The study recorded the participants' Mismatch Negativity (MMN) responses to stimuli before and after training. The results showed that listening training improved participants' ability to discriminate and identify an unfamiliar contrast, as reflected in an increased MMN. This study suggests that the perceptual system retains its ability to perceive speech sounds, and rapid improvements can occur after exposure to new foreign sounds. These findings support the SLM's notion that even late adults can enhance their non-native speech perception abilities (Sebastián-Gallés, 2005).

Indeed, despite the plasticity of speech learning abilities, second language learners may still encounter difficulties in perceiving specific foreign sounds. For instance, a study by Takagi and Mann (1995) examined native Japanese speakers who had resided in an English-speaking country for over a decade and were exposed to English on a daily basis. These participants still performed below native English speakers in distinguishing sounds like /r/ and /l/, which are phonemically distinct in English but not in Japanese. Similarly, Bosch, Costa, and Sebastian-Gallés (2005) found that even early bilingual speakers, who acquired their second language at a young age, still exhibited advantages in perceiving and processing their first language compared to their second language. These studies highlight that individuals with extensive exposure and high proficiency in their second language may still differ in performance when compared to native speakers (Sebastián-Gallés, 2005).

2.4.4 The rhythm of different languages

The properties of different languages can be categorized based on their rhythms, which can significantly impact language perception (Sebastián-Gallés, 2005). In multilingual environments, we often notice distinct differences between spoken languages, but sometimes we may struggle to recognize that different languages are being spoken. For example, without any lexical knowledge, it may initially be challenging to distinguish between German and Dutch (Sebastián-Gallés, 2005). However, we may have less difficulty distinguishing between French and English or Italian and Japanese (Sebastián-Gallés, 2005). The rhythm of a language plays a role in these patterns of confusion. It has been demonstrated that the ability to discriminate between languages based on their rhythm develops early in infancy and can assist individuals in overcoming difficulties when listening to foreign languages (Sebastián-Gallés, 2005).

The classification of languages based on their rhythms was first proposed by Pike (1945). He distinguished between stress-timed and syllable-timed languages. Stress-timed languages exhibit regular intervals between syllables, while syllable-timed languages have isochrony (similar perception time) at the syllable level. Over time, this classification has been refined as researchers acknowledge the complexity of real speech and propose more sophisticated models (Sebastián-Gallés, 2005).

Ramus et al proposed that the rhythm of language can be classified as a combination of signals corresponding to vowels and consonant groups (Ramus, Nespor, & Mehler, 1999). Another study addressed the effect of language rhythm on speech perception by investigating cross-linguistic adaptation to time-compressed speech (Sebastián-Gallés, 2005). Participants were exposed to time-compressed signals from different languages, and their adaptation to signals from their first languages was measured for comparison. The results of the study confirmed the importance of language rhythm in determining adaptation to compressed speech.

The rhythmic properties of the language can influence the perception of foreign language speech (Sebastián-Gallés, 2005). Even if foreign speakers have consistent proficiency of a language in terms of lexical and syntactic levels, they may still be less easily understood by native listeners. This is because the perception process is influenced by both the native language of the speaker and the native language of the listener (Bent & Bradlow, 2003). For instance, Spanish listeners may find it easier to understand native speakers of Italian or Greek compared to native speakers of Japanese or German.

2.4.5 The influence of language experience

Research on the categorical nature of tone perception has investigated the influence of language experience, particularly in tonal and non-tonal languages (Xu et al., 2006). For instance, cross-language comparisons have demonstrated that native Mandarin speakers perceive the contrast between Mandarin Tone 2 (high rising) and Tone 1 (high steady) categorically, whereas non-native Mandarin speakers do not (W. S. Wang, 1976). Additionally, a recent study comparing Taiwanese and French speakers found that there might be a gradient in the degree of categorical perception in cross-language perception of lexical tones (Hallé, Chang, & Best, 2004). Specifically, when comparing tonal continua in Taiwanese (e.g., ranging from Tone 1 to Tone 2), Taiwanese speakers exhibited a higher degree of categorical perception in tone perception compared to non-tonal French speakers. Categorical perception encompasses two perspectives: identification and discrimination. Measurements such as peak of identification response time, slope of identification curve, and peak of discrimination performance vary based on the listener's familiarity with lexical tone (Hallé et al., 2004). However, despite their lack of familiarity with lexical tones, French speakers still demonstrate the ability to make identification and discrimination judgments based on psychophysical factors (Hallé et al., 2004). This can be explained by the Perceptual Assimilation Model (PAM), which posits that categorical perception, based on a speech model of perception, is achieved depending on one's native phoneme categories (Liberman et al., 1967). Therefore, when French speakers perceive lexical tones in Taiwanese, they do so in a non-categorical manner, as these lexical tones cannot be assimilated into the phonemic units of French. Thus, the language-specific phonetic perception processes specific to French are not invoked.

2.4.6 Differences between Mandarin and English

Prosody is an acoustic cue in speech that provides information about lexical meaning, emphasis, and grammatical structure, and affects discourse structure (Edelson & Diehl, 2013). As a suprasegmental element of speech, prosody encompasses the rhythm and melody of the voice, including intonation patterns, pauses, and stress (Edelson & Diehl, 2013). Intonation refers to the melodic contour of the voice and is often referred to as "pitch" from an acoustic perspective, which corresponds to the fundamental frequency (F0) of the voice (Wagner & Watson, 2010).

The study of tonal languages has generated interest in suprasegmental features of speech, such as pitch. Mandarin is a typical tonal language, while English is non-tonal. In Mandarin, prosody, specifically the pitch contours (tones) of syllables, is used to differentiate lexical meanings, whereas in English, pitch is more commonly employed to convey emphasis or other linguistic features, such as questioning (Duanmu, 2004; Li, Tang, Lu, Wu, & Chang, 2021). Mandarin consists of four contrasting pitch contours: Tone 1 (high and steady), Tone 2 (high rising), Tone 3 (falling and rising), and Tone 4 (high falling and neutral) (Cheng, 1991). This difference between Mandarin and English may lead to language-specific perception of lexical tones. For instance, speakers of tonal languages like Mandarin and Cantonese demonstrate superior discrimination abilities for tones compared to English speakers (T. Huang & Johnson, 2011; Lee, Vakoch, & Wurm, 1996).

The contribution of consonants and vowels in Mandarin and English differs (Zhao, Jiao, Wang, & Wei, 2022). In English, there are 19 syllabic "phonemes," including 11 simple vowels, 5 syllabic consonants, and 3 diphthongs. Additionally, English has 24 non-syllabic "phonemes" (Tiee, 1969). Typically, an English monosyllabic word consists of a syllabic phoneme in the central part, with optional initial and terminal parts consisting of nonsyllabic phonemes (Tiee, 1969). On the other hand, Mandarin has 20 syllabic phonemes, including 6 simple vowels, 9 diphthongs, and 5 triphthongs, along with 22 nonsyllabic phonemes (Tiee, 1969). Unlike English, in Mandarin, nonsyllabic phonemes never occur in initial or final positions (Tiee, 1969). In terms of lexical processing, English tends to rely more on consonants, whereas Mandarin places more emphasis on vowels (Wiener, 2020).

Another distinction between Mandarin and English lies in their syllable structures. Mandarin syllables do not contain consonant blends or clusters (Hashimoto, 1972), whereas English syllables do (e.g., "black"). Furthermore, each language possesses phonemes that are not present in the other. For instance, English has the sound /*v*/, which Mandarin lacks, whereas

Mandarin has /ü/, which is not found in English. Additionally, Mandarin has fewer voiced consonants compared to English (Kang, 1998). English syllables consist of a higher number of voiced consonants and a lower number of voiceless consonants than Mandarin (Lin & Wang, 1992). Moreover, monosyllabic words in Mandarin are typically structured as consonant-vowel, while English syllables allow for consonants to appear in the onset and coda positions (Du, Shen, Wu, & Chen, 2019).

Studies have also discovered differences in the Frequency Importance Function (FIF) between English and Mandarin (Chen, Huang, & Wu, 2016). The FIF describes the contribution of each frequency band to speech intelligibility (Chen et al., 2016). Their research on testing the FIF of Mandarin and English, using phonetically balanced monosyllabic words, revealed that frequency bands ranging from 1000 to 2500 Hz have relatively high importance for both languages (Chen et al., 2016). One possible explanation for this is that this frequency range encompasses most vowels, which are crucial for recognizing voiced sounds. Furthermore, it was found that the FIF of Mandarin is larger than that of English for frequency bands centred at 160, 1600, and 2000 Hz, indicating that these frequency bands are more critical for Mandarin than for English (Chen et al., 2016). The band centred at 160 Hz is likely due to the fact that the fundamental frequency (F0) of Mandarin is typically conveyed through low-frequency components (Moore, Glasberg, & Peters, 1985).

By referring to the Mandarin speech banana audiogram (Figure 3) and the English speech banana audiogram (Figure 4) (UCSF, 2023), it can be observed that the frequency range for Mandarin initials and finals does not extend beyond 3000 Hz, while English includes certain consonants (e.g., fricatives) that can reach frequencies up to 6000 Hz (Hu, Li, & Lau, 2019). Therefore, understanding Mandarin relies less on high frequencies, and low-frequency sounds are more crucial for comprehending Mandarin compared to English (Hu et al., 2019).

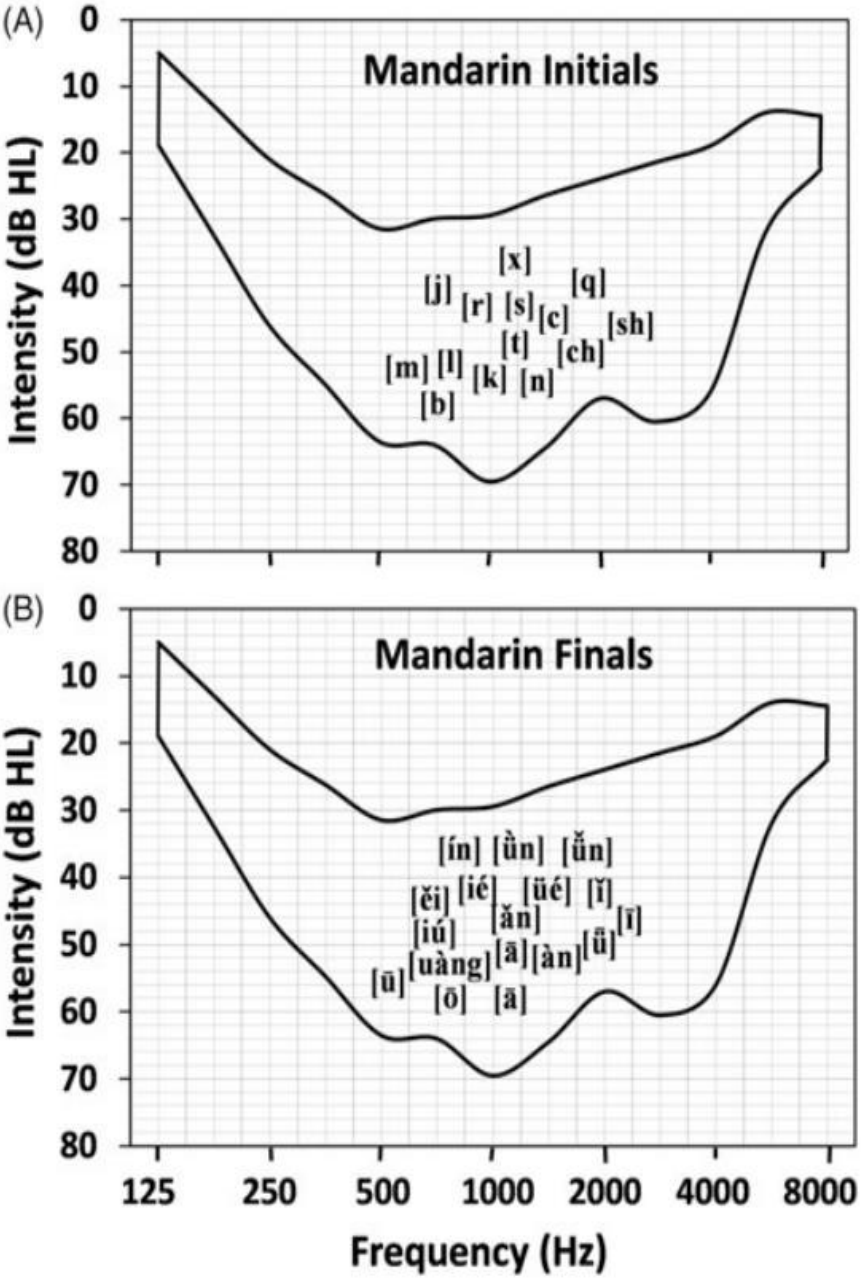

Figure 3: The Mandarin speech banana for initials (A) and finals (B)

(Retrieved from 'Development of the Mandarin speech banana' by Hu et al, (2019).
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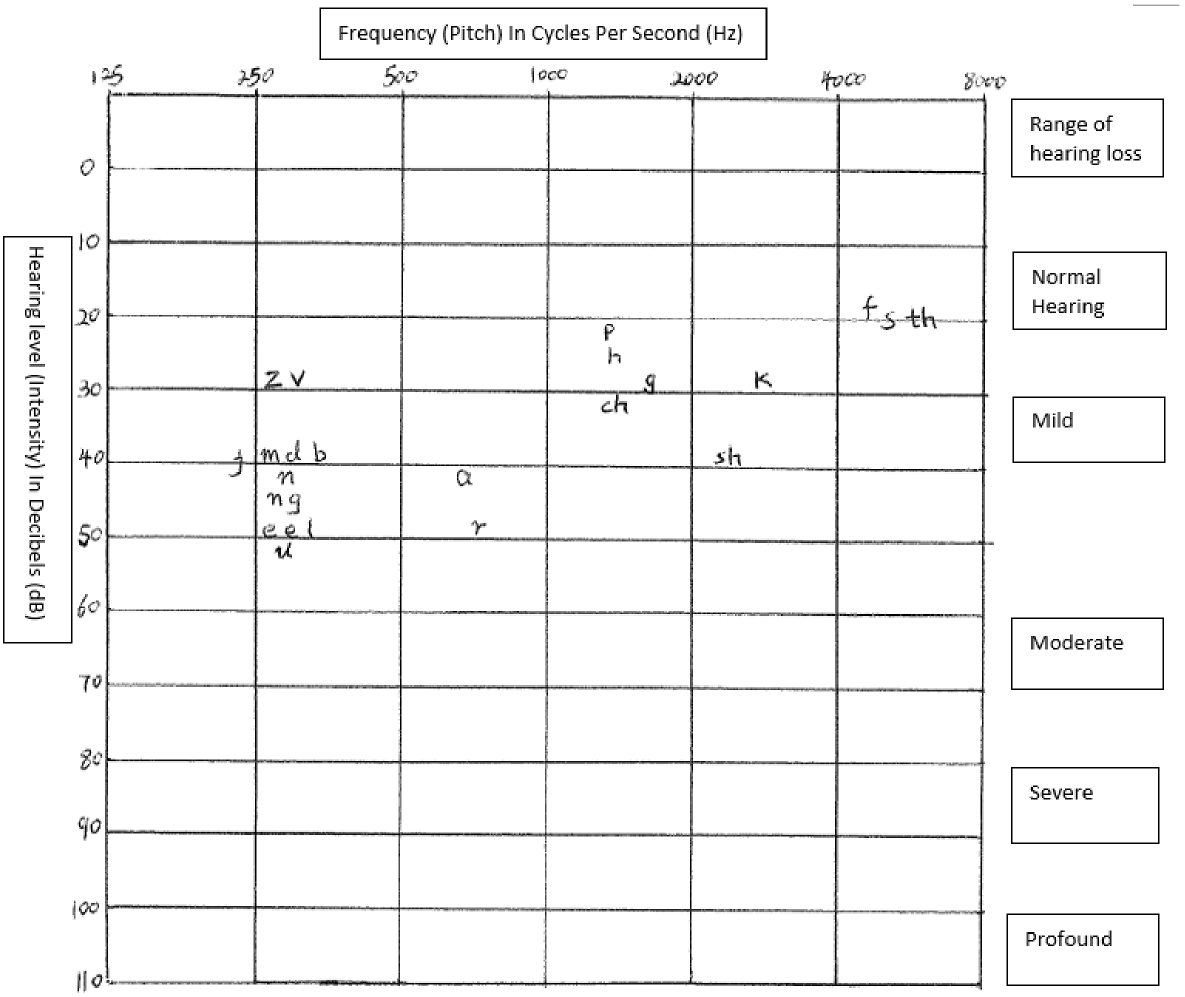

Figure 4: English speech banana audiogram

(Retrieved from *https://ohns.ucsf.edu/audiology/education/peds*. © UCSF)

2.5 Speech perception with hearing impairment

2.5.1 Hearing impairment

In 2015, 22% of people aged over 65 years old were significantly affected by hearing impairment, and this percentage has almost tripled compared to 15 years ago (Exeter, Wu, Lee, & Searchfield, 2015). The incidence and severity of hearing loss increase as people age over 65 years old, with elderly people accounting for 80% of hearing loss cases (Gates & Mills, 2005). It is expected that the total number of people with hearing loss in New Zealand will double in the next 50 years (Exeter et al., 2015), mainly as a result of the aging population.

Today, more people are able to live longer lives due to improved nutrition and healthcare (Huang & Tang, 2010). However, along with increased longevity, issues related to aging societies are also emerging. In China, a developing country, the population aged over 65 years old accounted for 7.69% in 2005 (CNBS, 2006), and it is expected to increase to 25% by 2050. In America, a developed country, the percentage of people over 65 years old was 12.4% in 2004 and is projected to reach 20% by 2030 (Haber, 2019). As the proportion of the elderly population (individuals aged 65 years old and above) increases, it is anticipated that the number of individuals experiencing age-related hearing loss will also rise.

Hearing impairment refers to the loss of audibility on the audiogram, which is crucial for speech perception (Alexander, 2021). This condition can occur at any age, and the age at which hearing impairment manifests can vary (Curhan & Curhan, 2016). The causes of hearing impairment are complex and can involve various factors such as aging, environmental influences, genetics, epigenetics, health comorbidity, lifestyle, diet, or interactions among these factors. In children, hearing loss can impact speech development and learning, while in adults, it can affect their social and professional lives (Bahmad, 2015).

2.5.2 Hearing impairment classification

Hearing loss can be classified based on the degree, type, and configuration of the impairment. The degree of hearing loss is categorized as slight (16-25 dB HL), mild (26-40 dB HL), moderate (41-55 dB HL), moderate to severe (56-70 dB HL), severe (71-90 dB HL), and profound (90 dB HL and above) (Katz & Lezynski, 2002) (Table 1). People with mild hearing loss typically start experiencing difficulty in following normal conversations (Bahmad, 2015).

Table 1: Classification of degree of hearing loss

Hearing Level (dB HL)	Hearing Loss Label
10 to 15	Normal Hearing
16 to 25	Slight hearing loss
26 to 40	Mild hearing loss
41 to 55	Moderate hearing loss
56 to 70	Moderate to severe hearing loss
71 to 90	Severe hearing loss
90 and above	Profound hearing loss

(Source: Katz and Lezynski (2002))

Hearing loss can also be categorized into different types: conductive hearing loss, sensorineural hearing loss, and mixed hearing loss. Conductive hearing loss occurs when there is a dysfunction in the middle or outer ear, preventing sound from effectively transmitting from the outer ear to the inner ear (Bahmad, 2015). Sensorineural hearing loss refers to dysfunction in the inner ear or the neural pathways beyond the inner ear (Bahmad, 2015). Mixed hearing loss is a combination of both conductive and sensorineural hearing loss.

The configuration of hearing loss refers to the shape of the audiogram across the frequency spectrum, indicating the frequencies at which individuals hear best and worst (Bahmad, 2015). A flat configuration implies that the hearing loss is relatively consistent across all frequencies, appearing as a horizontal line on the audiogram (Bahmad, 2015). Individuals with a flat hearing loss require similar loudness to hear sounds regardless of their pitch (Bahmad, 2015). On the other hand, a sloping configuration indicates a threshold increase of 5-20 dB per octave (Section of Audiology, 2021). In a high-frequency sloping configuration, individuals may exhibit good hearing in low frequencies but poor hearing in high frequencies (Bahmad, 2015), which is commonly seen in age-related hearing loss.

Hearing loss associated with aging, known as presbycusis, can range from mild to profound (Huang & Tang, 2010). People with presbycusis often experience high frequency hearing loss, significantly affecting their communication, especially in noisy environments. When the hearing loss extends to the frequency range of 2-4 kHz, voiceless consonants (such as /*t*/, /*p*/, /*k*/, /*f*/, /*s*/, and /*ch*/) become significantly affected, leading to difficulties in speech understanding (Huang & Tang, 2010). This is why many older individuals often complain that they can hear someone's voice but cannot understand the speech, as their speech perception may have diminished.

2.5.3 Hearing test

Hearing screening, such as pure tone audiometry (PTA), is a valuable tool for evaluating hearing loss. PTA, considered the gold standard, is conducted in a soundproof chamber or quiet room to assess individuals' hearing at different frequencies. PTA thresholds represent the lowest level at which individuals can respond to a tonal stimulus, providing information about the type, configuration, and degree of hearing loss (Schlauch & Nelson, 2009). However, PTA is not sufficient to assess speech comprehension difficulties, so audiologists typically complement it with a speech recognition test (SRT) to validate the PTA results (Schlauch & Nelson, 2009).

In clinical practice, audiologists often use word recognition tests, specifically Consonant-Vowel-Consonant (CVC) words developed from the AB test by Arthur Boothroyd

(Boothroyd, 1968) (Myles, 2017). CVC words are monosyllabic words in English that are designed to be phonemically balanced and phonetically balanced, meaning that each phoneme occurs equally and the frequency of phoneme occurrence is consistent with their usage in the English language. During the speech recognition test, patients listen to these words and repeat them aloud. The results provide valuable information about patients' ability to detect, recognize, or understand speech and guide subsequent rehabilitation options.

Similarly, Mandarin also has a speech recognition test with disyllabic materials for speech audiometry that demonstrates sufficient reliability and validity for clinical use (Wang, Mannell, Newall, Zhang, & Han, 2007). The disyllabic words used in Mandarin materials are also phonologically balanced and familiar to the language users (S. Wang et al., 2007). In Mandarin, each character is typically represented by a single syllable phonologically, and disyllabic words are formed by combining two monosyllabic words, each consisting of an initial consonant (optional) and a final with a suprasegmental tone (Han et al., 2009).

2.5.4 Speech perception with hearing impairment

People with poorer hearing thresholds often encounter difficulties in speech perception in various scenarios, including speech with background noise, speech at a distance, speakers with soft voices, or communication over the phone (without visual cues) (Souza, 2016). Compared to individuals with normal hearing, those with hearing impairment tend to perform worse when attempting to perceive speech in noisy environments. People with normal hearing can leverage the temporal dips in background noise to aid in speech perception. Temporal dip refers to the fluctuations in overall signal-to-noise ratio, particularly when the signal strength surpasses the background noise (Shetty, 2016). This temporal dip allows for a momentary "glimpse" of the target speech (Shetty, 2016). However, individuals with hearing impairment often have limited or no ability to effectively utilize these temporal dips to enhance speech perception, even with the assistance of hearing aids that amplify sound (Lorenzi, Gilbert, Carn, Garnier, & Moore, 2006).

Generally, the severity of hearing loss directly correlates with the level of difficulty in speech perception (Moore & Popelka, 2016). However, it is important to note that speech perception abilities can vary among individuals with similar hearing loss as indicated on the audiogram. It has been suggested that different patterns of damage in the inner ear can have varying effects on speech perception. While some individuals may have similar hearing thresholds, the specific damage to their inner ears can impact their speech perception differently.

Usually, outer hair cells in the cochlea are often more susceptible to damage from noise exposure or exposure to ototoxic agents, whereas inner hair cells and outer hair cells can be affected by disruptions in the endocochlear potential. In terms of speech perception, the loss of outer hair cells can result in reduced frequency selectivity. Damage originating in the cochlea tends to cause broader auditory filters and tuning, leading to a reduced number of auditory channels available to encode specific speech signals (Souza, 2016). This reduction in frequency selectivity further impairs speech perception. Specifically, when listening to speech in the presence of background noise, reduced frequency selectivity is associated with increased masking, making it more difficult to discern speech targets from the noise.

Temporal envelope and temporal fine structure are essential components of acoustic signals (B. Li et al., 2015). Within the cochlea, complex sounds like speech and music are divided into narrow frequency bands by the peripheral auditory system (Moore, 2019). The temporal information within each band can be classified as the temporal envelope and temporal fine structure, which respectively represent changes in sound amplitude and frequency (Moon & Hong, 2014). Both the temporal envelope and temporal fine structure play important roles in speech perception, particularly in perceiving pitch and loudness (Moon & Hong, 2014).

Research has indicated that speech recognition in quiet is primarily influenced by the temporal envelope, while the temporal fine structure is more crucial for speech perception in noisy environments (Hopkins & Moore, 2009). Therefore, it is assumed that individuals with sensorineural hearing loss may experience difficulties with the perception of temporal fine structure. Studies have also demonstrated the presence of an "off-channel" effect in patients with high-frequency hearing loss, where the impairment extends beyond the frequency range of the hearing loss and affects lower frequency regions where thresholds may still be within the normal range (B. Li et al., 2015).

2.6 Speech perception in noise

2.6.1 Noise and masking

In everyday listening situations, speech is often accompanied by background noise, and understanding speech in noise is generally more challenging than in quiet environments. While individuals with normal hearing can achieve near-perfect accuracy in recognizing speech in quiet, their performance declines as the level of background noise increases (McCreery & Stelmachowicz, 2011). The concept of the "cocktail party problem" was introduced by Cherry in 1953 to describe the difficulty listeners face in segregating speech from background noise. In noisy environments, multiple voices often overlap in frequency and time, directly interfering with each other and affecting speech perception (Bee & Micheyl, 2008). This interference of noise on speech perception is known as masking. Masking occurs when the frequencies of the target speech and the background noise cannot be separated, resulting in a failure of frequency selectivity (Oxenham & Wojtczak, 2010).

To better understand the effects of speech perception in noise, different perspectives of auditory masking are considered. Suppression is one mechanism that may be responsible for masking. It refers to the reduction in neural response to a stimulus when another stimulus is presented simultaneously (Rodríguez et al., 2010). Suppression of masking can be measured by observing the decrease in neural activity evoked by the target signal in the presence of the masker. Another masking mechanism is excitation, which was traditionally considered the primary mechanism of simultaneous masking according to psychoacoustics. It involves the spread of neural excitation evoked by the masker to the place along the cochlea corresponding to the frequency of the target signal (Delgutte, 1990). Simultaneous masking, also known as frequency masking or spectral masking, refers to masking that occurs in the frequency domain. Non-simultaneous masking, on the other hand, occurs in the time domain when masking sounds precede or follow the target signals (Kludt, Nogueira, Lenarz, & Buechner, 2021). In the present study, the focus is primarily on simultaneous masking, as it is most relevant to research where masking noise is present concurrently with the signals.

Everyday situations involve a wide range of noise levels, from quiet environments like homes or offices to noisy environments like public transportation or restaurants (Olsen, 1998). These various levels of noise can affect speech perception through masking (X. Wang & Xu, 2021). There are two main types of masking that can interfere with speech signals: informational masking and energetic masking (Lidestam, Holgersson, & Moradi, 2014). Informational masking occurs when both the masking noise and the speech signal are audible, but the listener is unable to disentangle the target sound from the distracting sounds (Brungart, 2001). It involves higher-level processing and can impact both peripheral auditory processing and cognition level. In a cocktail party, even if the concurrent speeches do not overlap with the target signal, either in frequency or time, the perception of speech can still be impaired due to informational masking (Bee & Micheyl, 2008).

On the other hand, energetic masking occurs when the physical properties of the noise interfere with the perception of the speech signal. This type of masking makes the speech signal inaudible at the peripheral auditory level (Brungart, 2001). Energetic masking is mainly determined by the spectral overlap between the masking noise and the speech signal, and as the speech-to-noise ratio decreases, speech recognition performance decreases accordingly (Brungart, 2001). For example, white noise, which covers all frequencies, causes energetic masking by mechanically interfering with the speech signal along the auditory pathway (Van Engen, 2010).

2.6.2 Speech perception in noise

To have effective communication in a noisy environment, we often need to rely on perceptual mechanisms. One such mechanism that humans can depend on to solve the "cocktail party problem" is auditory scene analysis (Bee & Micheyl, 2008). Auditory scene analysis refers to the process of parsing a mixture of sounds into neural representations to maintain the integrity of distinct sound sources (Sussman, 2017). Auditory scene analysis encompasses two groups: sequential integration and simultaneous integration (Bee & Micheyl, 2008). Sequential integration involves the ability to integrate sounds from one sound source into a coherent auditory stream while simultaneously segregating them from sounds from other sound sources (Bee & Micheyl, 2008). Simultaneous integration refers to the perceptual grouping of different sounds that occur simultaneously into individual sound sources while separating them from other sounds in the environment (Bee & Micheyl, 2008).

When perceiving speech in a noisy environment, humans need to perceptually segregate sequences of speech sounds, such as syllables or words, spoken by different individuals (Bee & Micheyl, 2008). The result of a coherent succession of sounds is referred to as an auditory stream. Auditory streaming involves two processes: stream integration and stream segregation (Bee & Micheyl, 2008). Stream integration occurs when the auditory system combines sounds occurring at different times into the same ongoing stream, while stream segregation involves separating the target sound from sounds simultaneously produced by other sources (Bee & Micheyl, 2008).

During speech processing in noise, the ability to compensate for poor listening environments can vary depending on whether the listener is listening to their native language or a foreign language (Sebastián-Gallés, 2005). When listening to a foreign language, noise or distortion tends to have a greater impact on speech perception compared to listening to one's first language (Sebastián-Gallés, 2005). This difference may be due to individuals having a larger lexicon and more efficient syntactic abilities in their first language.

2.6.3 Speech in noise test

The clinical tool used to objectively evaluate speech recognition ability in noise is the speech-in-noise test. These tests typically involve presenting speech materials along with background noise (Whitmer, Wright-Whyte, Holman, & Akeroyd, 2016). The speech materials can consist of syllables, words, sentences, and other linguistic units, while the type of noise can vary and include babble noise and stationary noise. During the test, listeners are asked to repeat back or identify the contents of the speech signals they hear after each presentation. The choice of speech testing materials can influence individuals' performance in speech recognition in noise.

Despite the potential benefits of speech-in-noise tests in assessing speech recognition in noise and aiding in hearing aid settings, they are not commonly used in routine clinical practice (Davidson, Marrone, & Souza, 2022). A survey showed that only 10% of audiologists regularly use QuickSin, which is the most widely used speech-in-noise test in clinical settings (Mueller, 2016). QuickSin, with its quantitative design, allows for the quantifiable interpretation of hearing aid effectiveness (Whitmer et al., 2016). Speech-in-noise tests simulate speech understanding in noise and provide a percentage of change in speech recognition at different signal-to-noise ratios (SNR). This objective measure can provide valuable information to complement self-report questionnaires and help set realistic expectations for potential improvements with hearing aids (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004).

2.7 Provisions of hearing aids

2.7.1 Introduction to hearing aids

There are two main perspectives regarding the effects of hearing loss on speech perception (Phatak, Yoon, Gooler, & Allen, 2009). The first perspective is the loss of audibility, which suggests that individuals with hearing loss require higher sound levels to hear effectively (Phatak et al., 2009). Modern hearing aids with multichannel non-linear amplification can effectively address this audibility loss. The second perspective is the difficulty in speech perception in noise (Phatak et al., 2009). This difficulty is often referred to as 'distortion' (Plomp, 1978) or 'SNR loss' (Killion, 1997). SNR loss, also known as "signal-to-noise ratio loss", related to the reduced performance in supra-threshold conditions, particularly in challenging listening environments with background noise. It means the increase in signal-to-noise ratio required for a listener to achieve 50% correct word or sentence recognition (Killion, 1997). It has been observed in clinical settings that individuals with similar Pure Tone Average (PTA) hearing loss may experience different difficulties in hearing in noise when using hearing aids (Killion et al., 2004). This is because individuals with similar PTA hearing loss can have different levels of SNR loss. Therefore, understanding a patient's SNR loss is crucial for professionals to provide appropriate recommendations and select the most suitable hearing aid modalities for individual patients.

People with hearing loss often seek assistance from hearing aids or other assistive devices to improve audibility and speech intelligibility. The primary goal of hearing aids is to amplify and process sound for individuals with hearing loss, compensating for their hearing impairment (Petersen et al., 2022). When prescribing hearing aids, audiologists consider factors such as the individual's pure-tone audiogram and loudness discomfort level (Souza, 2016). For instance, in cases of high-frequency hearing loss, the configuration of the hearing aids must be carefully selected to minimize potential feedback, which is the whistling sound caused by the microphone being too close to the speaker.

Hearing aids typically consist of three main components: a microphone to capture the acoustic signal, a digital signal processor that performs functions such as amplitude compression and limiting, noise reduction, feedback cancellation, or frequency-dependent amplification, and a receiver that converts the processed signal into sound (Figure 5). Clinically, hearing aids have shown to provide significant benefits for individuals with mild to moderate hearing loss (Moore & Popelka, 2016). However, for individuals with severe sensorineural hearing loss, the benefits of hearing aids may be limited, as they often have very limited auditory function and reduced ability to discriminate words even when presented well above their detection thresholds (Moore & Popelka, 2016). In such cases, cochlear

Figure 5: Hearing aid main components

(Retrieved from https://www.bayaudiology.co.nz/hearing-aids/features-and-benefits/ampli-energy/ampli-energy-r-5. © Bay Audiology 2023)

2.7.2 Speech perception with hearing aids

Various factors can impact speech perception with hearing aids, including the acoustic environment, the characteristics of the assistive device, the listener's auditory system, and their cognitive abilities (Souza, 2016). Individuals with hearing aids, as a result of hearing loss, go through various stages of acoustic reception and speech processing, which correspond to the stages of sound transmission and processing.

When an acoustic signal is produced by a speaker, it is initially modulated by the acoustic environment, which may include factors like reverberation or background noise. The hearing aids, as assistive devices, pick up, modify, and amplify the acoustic signal. The modified signal is then processed within the auditory and cognitive systems of the hearing aid wearer. In the peripheral auditory system, the acoustic signal vibrates along the cochlea, stimulating the inner hair cells and the auditory nerve, and forming synaptic connections (Souza, 2016). If there is hearing loss due to the loss of hair cells, the conveyed acoustic information may be degraded. At the neural level, the firing rate of auditory neurons tuned to different frequencies can also influence the transmission of acoustic information (Souza, 2016). When the acoustic signal reaches the cognitive level, processes such as working memory come into play to construct the meaning of the signal.

People with hearing loss find it especially difficult to hear speech in a noisy environment, and hearing aids are therefore prescribed to help compensate for these hearing difficulties. As otological devices, the evolution and progress of hearing aids are driven forward by technological advancements. Hearing aids are not simply designed to make every sound loud; instead, they employ sophisticated designs and technologies to selectively enhance desired sounds. For instance, individuals with sensorineural hearing loss who have a narrower dynamic range of speech (from the threshold of audibility to the discomfort threshold) are less likely to benefit from linear amplification. This is because linear amplification can make high-intensity sounds uncomfortably loud or render low-intensity sounds inaudible for them. Therefore, hearing aids are intended to control the amplification of sound by attenuating the appropriate sounds at the right time, frequencies, and direction of arrival (Alexander, 2021). Through appropriate adjustment and modulation, hearing aids can amplify speech arriving from the front direction, making it easier for individuals to hear speech in noisy environments.

Clinically, many patients report difficulties in hearing speech in noisy settings, and hearing aids utilize two technical modalities to address this issue: directional microphones and digital noise reduction. Directional microphones have been a standard feature in hearing aids for nearly 40 years and have proven to be effective (Sung, Sung, & Angelelli, 1975). However, certain styles of hearing aids, such as completely-in-canal devices, may not include directional microphone features because their design does not prioritize capturing directional information (Souza, 2016). Directional microphones operate in the spatial domain and are particularly effective in enhancing speech recognition when the speech source and the noise source are spatially separated. Unfortunately, they tend to perform less favourably in scenarios involving multiple or moving noise sources, when the speech signal originates from behind the listener, or when sound sources come from different directions (Bentler & Chiou, 2006; McCreery & Stelmachowicz, 2011).

On the other hand, the "digital noise reduction" modality is designed to filter out unwanted noise while preserving the desired speech signals. Technically, noise reduction aims to improve the signal-to-noise ratio and reduce the impact of noise on sound quality and speech perception (Sarampalis, Kalluri, Edwards, & Hafter, 2009). It relies on analysing the modulation patterns of signals in each frequency band to distinguish between speech and noise components. It quickly reduces the amplification of noise while preserving the amplification of speech in different frequency regions (Souza, 2016).

However, the digital noise reduction modality is not infallible and may not always function perfectly. It can sometimes misclassify noise and speech within the same frequency band, particularly when the noise contains speech from other individuals in the surrounding environment. Digital noise reduction is a commonly employed feature in modern hearing aids, but its performance in noise suppression and speech enhancement may vary. Studies have suggested that digital noise reduction might not improve speech perception to the extent that patients expect (Bentler & Chiou, 2006), and the noise reduction feature of hearing aids may not significantly enhance speech intelligibility for listeners (Sarampalis et al., 2009).

Nevertheless, recent research has shown that the digital noise reduction modality can contribute to reducing listening effort and alleviating fatigue for patients listening in background noise (Souza, 2016). Listening effort refers to the cognitive exertion required to attend to and understand auditory information (McGarrigle et al., 2014).

2.7.3 Cognitive factors in hearing aids outcomes

Communication involves not only the peripheral auditory functions but also the cognitive processes required for selective attention, memory storage, comprehension, response generation, and resolving ambiguities (Sarampalis et al., 2009). In addition to the individual's hearing abilities, various cognitive factors can influence the outcomes of hearing aids (Shehorn, Marrone, & Muller, 2018). One such factor is working memory, which refers to the capacity to store and manipulate information for cognitive tasks (Cowan, 2014). Research has shown that older adults with hearing loss expend more listening effort for speech perception compared to older adults with normal hearing (McCoy et al., 2005). Therefore, when configuring hearing aids, it is important to consider the individual's cognitive abilities. As mentioned earlier, hearing aids can modify the acoustic signal. Individuals with lower working memory capacity may have a reduced ability to adapt to these modified signals and may require adjustments that optimize their cognitive processing capabilities.

The Ease of Language Understanding (ELU) model emphasizes the role of cognitive factors in speech processing. According to the ELU model, individuals with normal hearing sensitivity are faster at processing incoming speech signals compared to those with hearing loss (Shehorn et al., 2018). However, in the presence of competing noise or degraded speech signals due to hearing loss, there can be a mismatch between the incoming speech signals and the individual's lexical representations (Shehorn et al., 2018). To achieve speech understanding in such situations, explicit processing of the speech signals is necessary. The ELU model suggests that working memory is recruited during this explicit processing, but it comes at the cost of increased effort in speech perception due to additional processing of distorted speech signals (Shehorn et al., 2018). Moreover, when more cognitive resources are allocated to speech signal processing, fewer resources are available for deeper encoding of incoming information. Consequently, the speech context may not be effectively utilized, making it more challenging to compensate for the degraded signal.

2.7.4 Verification of hearing aids performance

The goal of hearing aids is to provide amplification to improve functional auditory ability (Munro & Mueller, 2016). Amplification should ensure that soft sounds are audible, conversational sounds are more intelligible, and intense sounds are not amplified to an uncomfortable level (Munro & Mueller, 2016). Various hearing aid prescriptions have been developed to provide amplification, but there is no specific validated prescription proven to be superior in benefiting patients' hearing (Munro & Mueller, 2016). Clinical studies have shown that a well-researched prescription, along with appropriate gain across frequencies, can result in enhanced speech intelligibility and improved satisfaction for patients (Munro & Mueller, 2016).

To ensure appropriate gain is provided to the patient's ear, real ear measurement (REM) is necessary. REM aims to accurately convert the hearing thresholds from the audiogram, transferring them from dB HL to hearing aids' output in dB SPL (Jorgensen, 2016). REM involves inserting a probe tube microphone into the ear to measure the hearing aid's output level reaching the ear. This process ensures that an accurate target gain is provided to the hearing-impaired patient, as the converted thresholds form the basis for calculation. Once the thresholds are converted through REM, a targeted prescription can be selected. Currently, the most popular hearing aid prescriptions are NAL and DSL (Jorgensen, 2016). NAL is primarily used to restore normal loudness perception and ensure signal clarity, while DSL aims to provide an audible signal and improve speech intelligibility.

2.7.5 Validation of hearing aids performance

After the verification process of hearing aids is completed, a validation process is followed to assess the patient's satisfaction with the hearing aids and determine whether they meet the individual user's needs (Moore & Popelka, 2016). The validation process involves asking patients about their perception of ear balance, sound quality, and comfort with the device (Jorgensen, 2016). Audiologists then make personalized adjustments based on each individual patient's comfort. While the verification process provides an average target for a particular patient group, it cannot guarantee individualized satisfaction (Jorgensen, 2016). In fact, some people may prefer louder sounds while others prefer softer sounds (Jorgensen, 2016). This is why both the verification and validation processes are necessary to balance audible sound amplification with the patient's specific preferences. In addition to the questions asked, self-report questionnaires are often used to evaluate the performance of hearing aids. These questionnaires assess aspects such as effectiveness of speech perception in quiet and in noise or reverberation, frequency of hearing aids use, sound quality, phone usage, auditory fatigue, loudness perception, binaural and spatial listening, residual activity limitation, and others (Moore & Popelka, 2016).

However, the assessment through questionnaires has its limitations. For example, it can be challenging to accurately assess the benefits of hearing aids in specific situations based solely on questionnaire responses. Respondents may focus more on the difficulties they experienced in those situations rather than highlighting the actual benefits (Moore & Popelka, 2016). Additionally, it can be difficult for respondents to accurately imagine and recall their listening experiences in those specific situations prior to being fitted with hearing aids, and this recall process may introduce biases (Moore & Popelka, 2016). As a result, it becomes challenging to compare their experiences before and after using hearing aids to determine the specific benefits provided by the devices in those situations.

So far, only a few questionnaires, among many others available, are extensively used in both research and clinical settings to validate the effectiveness of hearing aids. These include the APHAB (Abbreviated Profile of Hearing Aid Benefit), HHIE (Hearing Handicap Inventory for the Elderly), COSI (Client Oriented Scale of Improvement), GHABP (Glasgow Hearing Aid Benefit Profile), and IOI-HA (International Outcome Inventory for Hearing Aids). However, it is important to note that no single questionnaire is able to comprehensively cover all aspects of patients' experiences with hearing aids or provide an objective measurement of their effectiveness.

CHAPTER 3. AIMS AND HYPOTHESES

So far, the major literature pertaining to this research study has been reviewed. This chapter will concentrate on the aims and hypotheses of the study, as well as provide justifications of the research methodology.

3.1 Study rationale

New Zealand is a country known for its diverse ethnicities and languages, and the Chinese community is experiencing significant growth. According to statistics from 2018, there were 247,770 Chinese individuals in New Zealand, constituting approximately 5% of the total population (Stats_NZ, 2019).

To cater to the healthcare needs of the Chinese community, audiologists can ensure they conduct appropriate evaluations based on individual patient's needs. One of this research's aims is to enhance our understanding of how individuals perceive speech in both their native language and second language within a noisy environment. Additionally, it aims to validate the effectiveness of hearing aids prescribed in New Zealand for this specific population. The findings of this study may have significant implications for the prescription of hearing aids for individuals who speak Mandarin as their primary language and English as their secondary language.

Currently, the most common speech test clinically used by audiologists in New Zealand is the English speech recognition test with CVC words. CVC words are monosyllabic words in English, composed of a consonant-vowel-consonant (CVC) blend (e.g., 'dog'). However, not everyone living in New Zealand speaks English as their first language. The English CVC test might not be suitable for Chinese immigrants who speak Mandarin as their first language. Therefore, language-appropriate word sets may be needed.

3.2 Aims of the study

This research involved two phases. The first phase involved the development of a new set of test materials in Mandarin. The second phase aimed to investigate the benefits of New Zealand prescribed hearing aids in helping people identify English and Mandarin words in noise. To validate the effectiveness of our research, we measured the difference in the threshold of identification of English and Mandarin words in noise, both with and without hearing aids. Based on this, three main aims and associated hypotheses for this study were proposed.

Phase 1

Phase 1.1: Currently, there is no official, freely available Mandarin speech in noise test material in New Zealand. Therefore, in Phase 1, it is necessary to develop a Mandarin speech test set by recording and producing the Mandarin disyllabic word sets.

Aim 1.1: To develop and record Mandarin-language disyllabic word sets with consistent sound levels for use in phase 2 and potentially for clinical use.

Phase 2

Phase 2.1: Previous studies have indicated that non-native speakers generally exhibit lower performance in speech recognition in noise compared to native speakers, regardless of the type of speech stimuli, such as vowels, consonants, words, or sentences (Guan et al., 2021; Jin & Liu, 2012). Based on this, our research hypothesis is that participants would demonstrate better performance in Mandarin speech in noise compared to English speech in noise, as Mandarin is their native language.

Aim 2.1: To examine whether bilingual speakers (with Mandarin as their first language and English as their second language) who have hearing loss can achieve better word identification in noise in their first language compared to their second language.

Hypothesis 2.1: Individuals with hearing loss who are bilingual, with Mandarin as their first language and English as their second language, would demonstrate better word identification performance in the Mandarin speech in noise test compared to the English speech in noise test.

Phase 2.2: Hearing aids are commonly prescribed to individuals with hearing loss, as they provide sound amplification to enhance speech intelligibility (Souza, 2016). Additionally, hearing aids are equipped with various technologies aimed at reducing noise, improving sound quality, and benefiting speech intelligibility (Souza, 2016). Based on these findings, our hypothesis is that the use of hearing aids will result in improved thresholds for bilingual individuals in identifying Mandarin or English speech in noise.

Aim 2.2: To determine the extent to which New Zealand prescribed hearing aids provide benefits for bilingual speakers in their ability to perceive Mandarin and English speech in noise.

Hypothesis 2.2: The use of hearing aids would lead to improved thresholds for word identification in noise in both Mandarin and English.

Phase 2.3: English is the predominant language used in New Zealand, and most audiologists in the country primarily speak English. Due to limited opportunities to speak Mandarin and audiologists' potential lack of necessary linguistic knowledge in Mandarin, audiologists rely more on their English background for verification and validation of hearing aids for bilingual speakers. This reliance may potentially result in outcomes that predominantly benefit the English language. However, Mandarin and English have distinct language structures, encompassing differences in sound inventory, syllable structures, and frequency importance functions (FIF) (Chen et al., 2016). These differences in language structure may undermine the accuracy of hearing aid perception when a user is listening to Mandarin, particularly if the evaluation is solely based on performance in an English-language test.

Furthermore, it has been observed that the majority of patients with hearing loss experience greater difficulty in perceiving sounds in the high-frequency range. This suggests that they may face more challenges in identifying English words, as the English language relies more heavily on speech sounds in the high frequencies compared to Mandarin (Chen et al., 2016). As a result, it can be inferred that the ability to identify English words in noise is likely to improve to a greater extent than Mandarin, as hearing aid users receive more amplification in the high-frequency range.

Aim 2.3: To investigate whether New Zealand prescribed hearing aids provide similar benefits to individuals in perceiving speech in noise in their first language and second language.

Hypothesis 2.3: The use of hearing aids would result in a larger improvement in word identification thresholds in noise for English compared to Mandarin.

3.3 Methodology

3.3.1 Sound levels

In general, the distance between a speaker and listeners is approximately 1 metre, so participants were seated at this distance from the speaker. The average background level observed in schools was between 48-51 dBA. In a hospital setting, the average noise level in a patient's room is reported to be around 45 dBA (Olsen, 1998). The World Health Organization (WHO) recommended noise level in hospital wardrooms between 30-40 dBA (Schwela, 2001). Since all participants in this study have hearing loss, which can make it challenging for them to recognize speech in noise, particularly in their second language, the background noise level was set at 43 dBA (‘A’ frequency weighted and Fast Time weighting sound pressure level (LAF SPL)). This level was selected to ensure the task was feasible for all participants and represents the lower end of normal background noise.

The average level of speech in classrooms, hospitals, public transportation vehicles, and department stores typically ranges from 55 to 66 dBA, while in trains or airplanes, it can reach 73 to 77 dBA (Olsen, 1998). In the present research, considering that all participants have hearing loss, it was important to begin at a level where speech could be reliably identified. Therefore, the starting level of the speech stimuli was set at 80 ± 2 dBA.

3.3.2 Noise

The decision to utilize white noise instead of spectrally shaped noise or babble noise was based on the fact that white noise contains energy at all frequencies, effectively masking both languages. Babble noise introduces a combination of energetic and informational masking, and since the focus of the research was on the peripheral effects of hearing aids, it was not desirable to include an informational masking component that involves cognitive processes. Additionally, only English babble noise was available, and its masking effects on Mandarin speech may differ from its effects on English speech.

3.3.3 Counterbalance

The procedure of counterbalancing is employed to mitigate the influence of nuisance variables (Corriero, 2017). In the context of this research, if the same participants were repeatedly subjected to stimuli in the same order, the testing results could be affected by participants' adaptation (improvement) or fatigue (decline) over the course of the study. To circumvent this issue, a systematic variation of the testing session order (counterbalancing) was implemented in this research to avoid potential biases.

3.3.4 Speech identification

The materials used in this research consisted of English CVC (consonant-vowel-consonant) words and Mandarin disyllabic words. Words generally involve fewer cognitive factors or linguistic factors in perceiving speech in noise compared to sentences. This is because words have less predictability and contextual meaning, leading participants to rely more on their peripheral hearing abilities for word identification. Additionally, while sentences may be more representative of natural speech, they exhibit a larger dynamic range. Since this research specifically focuses on peripheral hearing, words were considered more suitable for this purpose.

In 2007, the Beijing Institution of Otolaryngology developed a disyllabic Mandarin speech test material, which has since been progressively implemented in clinics as a speech recognition test (Han et al., 2009). Audiologists can assess the accuracy of pure tone thresholds based on the test results (Han et al., 2009), and these results can also serve as an indicator of speech sensitivity (Hudgins, Hawkins, Kaklin, & Stevens, 1947). The majority of words in modern Mandarin are disyllabic, accounting for approximately 80% of word occurrences in contemporary Chinese (Zheng, 1987). Similar to English CVC words, Mandarin disyllabic words are commonly used in daily conversations and are highly familiar to Chinese speakers. Therefore, Mandarin disyllabic words were chosen as the testing material in this research.

Additionally, it should be noted that a single monosyllabic word pronunciation in Mandarin can be represented by multiple Chinese characters (Han et al., 2009). This characteristic has the potential to impact patients' performance in speech recognition tests when monosyllabic words are employed. Hence, monosyllabic words were not selected for use in this research. The disyllabic words used in this study were selected from the national standard of China (Center, 2010). Each disyllabic word represents a complete unit of meaning rather than separate monomorphemic units. Similarly, the English monosyllabic CVC words used in this research, like the Mandarin disyllabic words, are meaningful words (Boothroyd, 1968), making them suitable for comparison. Both Mandarin disyllabic words and English CVC words have been employed in clinical practice.

CHAPTER 4. METHOD

4.1 Phase one: Recording testing material

Currently, there is a lack of available Mandarin disyllabic speech in noise test material in New Zealand. Therefore, the student researcher, who is proficient in both Mandarin and English, recorded the Mandarin disyllabic words (Appendix 6) herself. In parallel, the student researcher followed the same procedure to record the English CVC words (Appendix 5). This approach ensured consistency and avoided potential inter-speaker variations, while also providing a parallel test material for comparing participants' hearing abilities in Mandarin and English words.

Recordings were conducted using the Voice Memos recording app on an iPhone XR. The audio files were saved securely on a password-protected computer. During the recording process, a sound level meter (B&K 2250) was positioned approximately 3 centimetres away from the iPhone microphone to ensure accurate sound level measurements. Each testing word was required to have a recorded sound level within the range of 68-72 dBA. If a word fell outside this range, it was re-recorded. This approach ensured that the words had a narrower range of levels compared to the University of Auckland Hearing and Tinnitus Clinic’s clinically used pre-recorded "CVC word lists" provided by a Grason-Stadler Inc Audiostar Pro (Grason-Stadler GSI Audiostar Pro Instruction Manual Rev C, 2014; Section of Audiology, 2021), which has a range of levels exceeding 4 dBA. Each recorded word was saved as an individual voice recording file, with a duration of approximately 1-2 seconds. The Mandarin disyllabic word set comprised 70 words, while the English CVC word set consisted of 72 words.

4.2 Equipment set up and calibration

The research was conducted in an audiology booth at the University of Auckland Hearing & Tinnitus clinic. The speech stimuli were played from a Lenovo Yoga 7 14ITL5 laptop and routed through the speech channel of an audiometer to a Mission M30 speaker within the booth. The UV meter was set to '0' prior to testing, and the initial level for each test was calibrated to start at 80 ± 2 dBA.

If any words exceeded the distortion limitation, which typically falls within the range of approximately -5 to 3 on the UV meter, they were identified, removed, and subsequently re-recorded. To ensure the accuracy of the recorded words, they were played to normally-hearing listeners who were native speakers of Mandarin or English. These listeners evaluated the phonetic pronunciation and clarity of the resounded sounds. If any words were subjectively deemed unclear or pronounced in a manner that could potentially cause confusion, they were either removed from the word set or re-recorded to ensure quality.

Throughout this validation process, a sound level meter was held by the listener to monitor and confirm that all words were presented within the appropriate range of 78-82 dBA. This step aimed to maintain consistency and ensure that the sound levels of the stimuli were within the desired range during the participant testing. Adaptive testing was performed to ensure that changing steps on the audiometer was reflected accurately in its output measured by the sound level meter.

4.3 Phase two: Participant recruitment

Participants were required to be bilingual speakers who spoke Mandarin as their first language and English as their second language. To be eligible for the test, participants needed to be over 18 years old, have a diagnosed hearing loss, and wear hearing aids prescribed in New Zealand.

Recruitment was primarily conducted using snowball sampling techniques, whereby participants assisted in contacting individuals they knew and informing them about the research (Reddy, Welch, Lima, Thorne, & Nosa, 2019). The student researcher leveraged personal networks, including platforms like Facebook and WeChat, as well as the University of Auckland participant recruitment website, to distribute advertisement flyers. Advertisement flyers were also targeted towards Chinese communities, specifically Mandarin-speaking churches. Local audiology clinics supported the recruitment efforts by presenting the advertisement flyers to their patients. Additionally, the student researcher visited local Sunday markets to distribute the advertisement flyers. These strategies were employed to reach potential participants and increase the awareness of the research within the targeted population.

The research received ethical approval from the Auckland Health Research Ethics Committee (reference number: 25367). Prior to participating in the research, participants were required to sign a consent form (Appendix 1). The research sessions were scheduled to accommodate the availability of the participants and the student researcher. As transportation was a challenge for more than half of the participants, the student researcher arranged car pick-up and drop-off services for these individuals, ensuring their convenience and participation in the study.

The initial planned size of participants for this research was 20. However, due to time constraints, a total of 19 participants were recruited. All participants met the eligibility criteria of being over 18 years old, speaking Mandarin as their first language, and English as their second language. Additionally, all participants had hearing loss and wore New Zealand prescribed hearing aids, which were fitted by an audiologist in New Zealand. To express gratitude for their participation, all participants received a $30 supermarket voucher.

The age range of the participants recruited for this study was 44 to 82 years old. Out of the 19 participants, 9 were female and 10 were male. Among the participants, two individuals wore a hearing aid in one ear due to profound hearing loss in the other ear, while the remaining 17 participants wore hearing aids in both ears.

4.4 Apparatus

The research was conducted in a sound-attenuating chamber. Participants were seated in a chair facing the loudspeaker 1 metre away. The top of the speaker was positioned 84 centimetres from the ground. All auditory signals were delivered through a Grason-Stadler Inc Audiostar Pro audiometer with the calibration due date on 21st November 2023 to the single loudspeaker. The background noise used in the study was generated by the audiometer and presented via the white noise channel. This setup ensured a controlled acoustic environment and allowed for precise delivery of the auditory stimuli during the research sessions.

4.5 Testing procedure

A simple, one-up-one-down tracking procedure was employed to determine the 50% correctness threshold for word identification, where participants could just identify the words of each session. During Phase 1, the recorded words were presented with white noise as the background noise. The research session consisted of four conditions, namely: English speech test with hearing aids on, Mandarin speech test with hearing aids on, English speech test without hearing aids on, and Mandarin speech test without hearing aids on. The testing procedure and threshold-chasing properties of the four sessions were identical.

The speech was initially presented at a level of 80 ± 2 dBA and adjusted based on the participants' responses. The maximum speech testing level is 95 dBA, which is within safety limitation (Mosoeuk, Weyers, & Rathebe, 2019). The background noise was continuously presented at a consistent level of 43 dBA. If participants correctly identified a word, the presentation level for the next word was decreased by one step. If participants identified a word incorrectly, the presentation level for the next word was increased by one step. The step size was 5 dB for the first 6 turnarounds and then reduced to 2 dB for the subsequent 6 turnarounds (Levitt, 1971). In tracking tasks, a turnaround refers to a series of steps in a single direction (upwards or downwards) (Levitt, 1971). The number of turnarounds is typically used as a basis for determining when to alter the step size or conclude the session (Levitt, 1971). The levels of the six turnarounds with 2 dB steps were averaged to estimate the 50% correct threshold, enhancing the reliability and accuracy of the final thresholds (Levitt, 1971). The tracking procedure concluded once thresholds for six turnarounds with 2 dB steps were obtained, indicating that the phonemic balancing property of the testing materials were less considered in this research since the entire word sets may not be tested.

After each word presentation, participants were given several seconds (approximately 5 seconds on average) to repeat what they heard. If participants were unable to repeat anything, the response was considered incorrect, and the next testing word was presented at a higher level. If participants provided an ambiguous response, they were asked to repeat or spell what they said.

4.6 Hearing aids

The hearing aid prescription data and the audiograms of participants were collected by connecting their hearing aids to the relevant software through NOAH. However, it was not possible to collect the data and audiograms through NOAH for three participants. As a result, data and audiograms were collected and processed for 16 participants.

4.7 Data processing and analysis

The 50% correct threshold for word identification in noise was determined by calculating the mean of the final six turnarounds, which were measured using a 2 dB step size. Each participant had four thresholds: Mandarin with hearing aids (M+HA) threshold, Mandarin without hearing aids (M-HA) threshold, English with hearing aids (E+HA) threshold, and English without hearing aids (E-HA) threshold.

The data analysis was conducted using IBM SPSS statistical software (v.26). To test the three main hypotheses, a 2x2 repeated-measures ANOVA was performed, with language (English and Mandarin) and hearing aid use (on or off) as the repeated measures. Hypothesis 2.1 was evaluated by comparing the Mandarin threshold with hearing aids on and off to the English threshold with hearing aids on and off. Hypothesis 2.2 was assessed by examining the overall effect of hearing aids across both languages. Hypothesis 2.3 was tested by analysing the interaction between language and the effect of hearing aids. If the improvement in threshold when using hearing aids for Mandarin is smaller than the improvement in threshold for English, it would support the idea that hearing aids fitted in New Zealand provide more benefit for participants in listening to English than Mandarin.

CHAPTER 5. RESULTS

5.1 Three main findings that align with the three hypotheses

5.1.1 Finding #1 - An overall effect of language

There was a significant difference between the thresholds of English speech in noise identification and Mandarin speech in noise identification (F(1, 18) = 110.050, $p < 0.001$) (Figure 6). In general, participants performed better in Mandarin speech in noise than in English speech in noise, regardless of whether they were wearing hearing aids or not. This result supports Hypothesis 2.1: "Individuals with hearing loss who are bilingual, with Mandarin as their first language and English as their second language, would demonstrate better word identification performance in the Mandarin speech in noise test compared to the English speech in noise test."

5.1.2 Finding #2 - An overall effect of hearing aids

Participants performed better at identifying words in noise in either language with hearing aids compared to without hearing aids (F(1, 18) = 85.363, $p < 0.001$) (Figure 6). This result supports Hypothesis 2.2: "The use of hearing aids would lead to improved thresholds for word identification in noise in both Mandarin and English."

5.1.3 Finding #3 - Interactions between the effects of hearing aids and language

There is no significant difference between the improvement of thresholds with the help of hearing aids in Mandarin speech in noise and in English speech in noise (F(1, 18) = 0.006, $p = 0.937$) (Figure 6). This finding does not support Hypothesis 2.3: "The use of hearing aids would result in a larger improvement in word identification thresholds in noise for English compared to Mandarin."

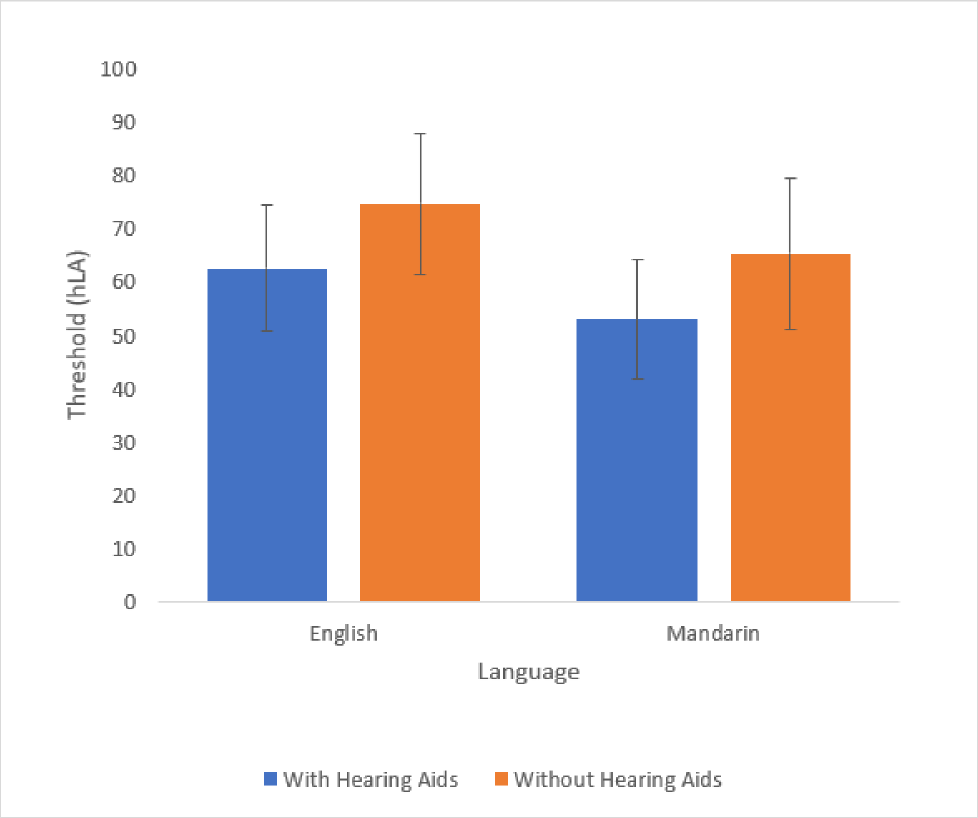

Figure 6: 50% correct word identification threshold for English and Mandarin words presented in noise with and without hearing aids (the error bars represent standard deviation)

5.2 Secondary analysis

To test the effect of the configuration of hearing loss on participants' speech recognition in noise, another model was developed. In this model, participants' hearing loss was categorized into "sloping hearing loss" (from low frequency to high frequency) and "flat hearing loss". According to the University of Auckland Master of Audiology Clinical Checklist (modified from Schlauch & Nelson, 2015), flat hearing loss refers to a < 5 dB slope on average per octave. Sloping hearing loss includes gradually sloping (threshold increases 5-12 dB per octave), sharply sloping (threshold increases 15-20 dB per octave), and precipitously sloping (flat or gradually sloping at first, then threshold increases ≥ 25dB per octave) (Schlauch & Nelson, 2009).

To categorize the participants' hearing loss into two groups ("sloping hearing loss" and "flat hearing loss"), this research took the general configuration of each participant's hearing loss (especially in the speech frequency areas 250-6000 Hz) as a criterion for categorization, and therefore utilized relative grouping strategies. It is worth noting that one participant in the "flat hearing loss" group had flat hearing loss in the left ear and gradually sloping hearing loss in the right ear, as the flat hearing loss was the more dominant hearing loss for the participant. This secondary analysis was based on 16 participants because audiograms for three participants were not available.

An analysis was conducted to determine whether there is an interaction between Language (Mandarin or English), Hearing Aid Use (with hearing aids on or not), and Hearing Loss Configuration (sloping or flat hearing loss).

5.2.1 Language * Hearing loss configuration

The analysis found that there was no interaction between the configurations of hearing loss and the languages in the speech in noise test (F(1, 14) = 0.01, *p* = 0.923). This means that the hearing loss configurations of the participants do not result in greater difficulty in hearing Mandarin or English speech recognition in noise.

5.2.2 Hearing aids use * Hearing loss configuration

No significant interaction was observed between the configuration of hearing loss and the use of hearing aids (F(1, 14) = 0.163, *p* = 0.693), indicating that the configuration of hearing loss does not impact the benefits provided by hearing aids.

5.2.3 Language * Hearing aids use * Hearing loss configuration

No three-way interaction was found among the three variables (F(1, 14) = 0.945, *p* = 0.348), indicating that the configuration of hearing loss does not influence the threshold of Mandarin or English speech recognition, regardless of whether the participants are using hearing aids or not.

5.2.4 Hearing loss configuration * Speech identification threshold

Though there was no three-way interaction between language, hearing aid use, and hearing loss configuration, the effect of the hearing loss configuration on speech identification thresholds was examined. The results revealed that, overall (regardless of language or hearing aid use), participants with sloping losses had slightly better thresholds compared to those with flat losses, although the difference was marginally significant (F(1, 14) = 3.190, *p* = 0.096) (Figure 7). This suggests that sloping hearing loss has a relatively smaller impact on participants' ability to hear speech in noise compared to those with flat hearing loss.

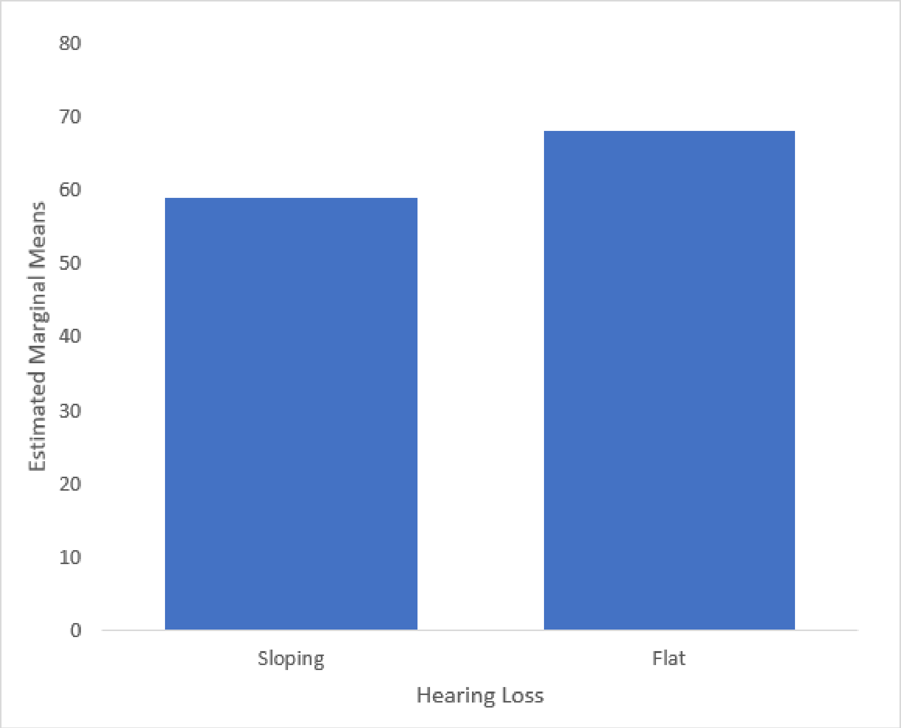

Figure 7: Overall effects of HL configuration on speech identification thresholds

5.2.5 Speech identification threshold (no hearing aids) * Hearing aid benefits

Another analysis was subsequently conducted to explore the association between participants' ability to identify words (without hearing aids) in noise and the hearing aid benefit (e.g., improvement in speech-in-noise identification threshold when wearing hearing aids) in each language. The correlations are shown as follows (Table 2):

Table 2: Participants' ability to identify words (without hearing aids) in noise and the hearing aid benefit

		M Benefit	E Benefit	M+HA	E+HA	M-HA	E-HA
E-HA	Pearson Correlation	0.478	0.446	0.838	0.864	0.885	1
	Sig. (2-tailed)	0.038	0.056	0.000	0.000	0.000	
	N	19	19	19	19	19	19
M-HA	Pearson Correlation	0.641	0.189	0.885	0.881	1	
	Sig. (2-tailed)	0.003	0.439	0.000	0.000		
	N	19	19	19	19	19	
E+HA	Pearson Correlation	0.266	0.065	0.961	1		
	Sig. (2-tailed)	0.271	0.792	0.000			
	N	19	19	19	19		
M+HA	Pearson Correlation	0.211	-0.047	1			
	Sig. (2-tailed)	0.386	0.847				
	N	19	19	19			
E Benefit	Pearson Correlation	0.475	1				
	Sig. (2-tailed)	0.040					
	N	19	19				
M Benefit	Pearson Correlation	1					
	Sig. (2-tailed)						
	N	19					

A marginal association was found between performance on the speech-in-noise task in English without hearing aids and the hearing aid benefit for English (r (19) = 0.446, *p* = 0.056) (Table 2). This implies that individuals who performed better at identifying English words in noise without hearing aids also experienced greater improvement in the same task when wearing hearing aids, although the effect is marginally significant. The threshold in Mandarin without hearing aids serves as a potential predictor of the hearing aid benefits for Mandarin (r (19) = 0.641, *p* = 0.003) (Table 2). This means that individuals who perform better in Mandarin speech recognition in noise without hearing aids also exhibit greater improvement when wearing hearing aids. The analysis also found that the ability to identify speech in noise, in both languages, with or without hearing aids, was highly intercorrelated (all r > 0.8) (Table 2). This means that if a participant had better thresholds in one of the four testing conditions, they tended to have better thresholds in the other three conditions.

In general, the hearing aid benefit in English and Mandarin showed a correlation with each other, although the correlation was only moderate (r (19) = 0.475, *p* = 0.04) (Table 2). This suggests that the improvement resulting from hearing aids is similar in both languages overall, but also somewhat language dependent for individuals.

5.3 Incidental finding

There was one exceptional case (participant X) who exhibited substantial benefit (23 dB) in English but did not experience any improvement in Mandarin (Figure 8).

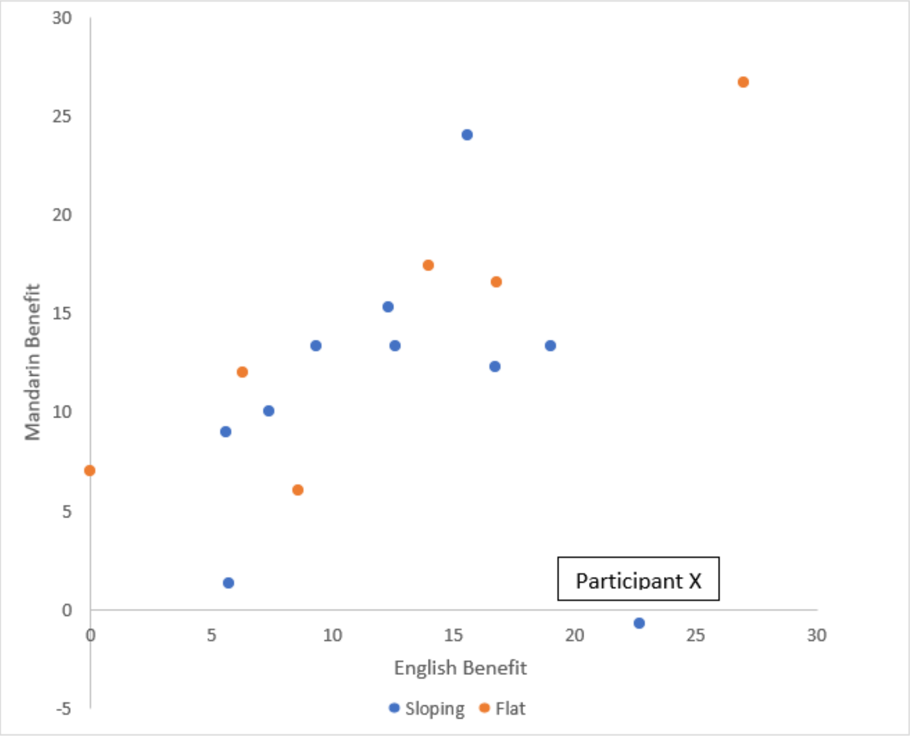

Figure 8: Configuration of hearing loss with the hearing aids benefits in hearing Mandarin and English

In fact, participant X had a sloping configuration of hearing loss, which differed from the majority of participants who also had sloping losses and followed the general pattern (Figure 8). This suggests that the correlation between the configuration of hearing loss, hearing aid benefit, and language can be individualized, and it requires further explanation.

CHAPTER 6. DISCUSSION

In this chapter, we will first investigate the findings with reference to the aims and hypotheses of the present research, and then delve into the aspects in greater details. We will also review the strengths and limitations of this research, as well as the clinical implications of the findings.

6.1 Examination of finding #1

Aim 2.1: To examine whether bilingual speakers (with Mandarin as their first language and English as their second language) who have hearing loss can achieve better word identification in noise in their first language compared to their second language.

Hypothesis 2.1: Individuals with hearing loss who are bilingual, with Mandarin as their first language and English as their second language, would demonstrate better word identification performance in the Mandarin speech in noise test compared to the English speech in noise test.

Finding #1: Participants demonstrated better ability to identify Mandarin speech in noise compared to English speech in noise, both with and without hearing aids.

This finding aligns with previous research indicating that individuals perform better in speech recognition in noisy environments when listening to their first language compared to their second language (Gat & Keith, 1978; Guan et al., 2021). This pattern holds true for various types of auditory stimuli, such as sentences, words, or vowels. One possible explanation is that individuals tend to process their second language slower and with less accuracy at different levels of speech processing, including phoneme identification, lexical recognition, and speech segmentation, especially when presented in noise (Cutler, Weber, Smits, & Cooper, 2004). Processing efficiency plays a crucial role in one's ability to perceive acoustic signals in noisy conditions (Cutler et al., 2004). Second language listeners often rely on their first language as a filter when listening to non-native speech, which is similar to PAM model, leading to perceptual difficulties/perceptual repairs and potential conflicts with their native language (Freeman et al., 2022). This temporary hindrance may result in slower response times and challenges in distinguishing sounds that do not exist in their first language (Freeman et al., 2022).

Consequently, due to lower processing efficiency and less accuracy in phoneme identification during second language processing, individuals often require a higher SNR for understanding second language stimuli compared to their first language stimuli (Cutler et al., 2004). Since both native and non-native speakers are affected by noise, a higher SNR leads to improved speech recognition performance, with non-native speakers experiencing a more significant impact. In the present study, white noise was presented at a fixed level. To achieve a higher SNR and reach the 50% correct threshold when listening to the second language (English), the speech level needs to be increased. Consequently, the present research results indicated that participants required averagely 12 dB higher speech level when listening to English speech in noise compared to Mandarin speech in noise, with and without hearing aids.

The relative perceptual advantage of a native language in speech perception is often associated with language experience (Zhang, Stuart, & Swink, 2011). Both receptive and expressive aspects of language are influenced by an individual's linguistic experience, such as the number of years exposed to a particular language (Strange & Jenkins, 1978). In the present research, almost all the participants started to learn English after 12 years old, and all of them use Mandarin as a daily communication language at home. Therefore, Mandarin is a more dominant language for them compared to English. Individuals’ language experience can shape their listening preferences and discriminatory abilities, ultimately impacting their speech perception (Kuhl, 2000). As a result, individuals tend to exhibit better perception of auditory stimuli that share temporal or spectral characteristics with their native language. In other words, the linguistic experience of Mandarin speakers, with their tonal language, grants them an advantage in perceiving stimuli with tonal features (Zhang et al., 2011).

In addition, the categorial perception of different languages can vary among native speakers, with native speakers being able to distinguish phoneme contrasts such as lexical tones that non-native speakers may struggle with. For instance, English listeners do not exhibit categorical perception between the first and fourth tones of Mandarin, whereas Mandarin speakers do (Wu & Lin, 2008). However, this property of categorical perception is significantly influenced by individuals' experience with their native language (L. Holt, 2009). For example, many Japanese speakers are unable to distinguish the English sounds /*r*/ and /*l*/ due to their experience with the phonetic structure of Japanese. Given the different phonetic structures of Mandarin and English, as well as the presence of sounds in English that Mandarin lacks, Mandarin speakers, like our participants, have greater familiarity and language exposure to Mandarin compared to English. Consequently, Mandarin speakers may encounter difficulty in perceiving certain sounds that exist only in English. This explains why participants exhibited poorer perception of English speech compared to Mandarin speech in noisy conditions.

6.2 Examination of finding #2

Aim 2.2: To determine the extent to which New Zealand prescribed hearing aids provide benefits for bilingual speakers in their ability to perceive Mandarin and English speech in noise.

Hypothesis 2.2: The use of hearing aids would lead to improved thresholds for word identification in noise in both Mandarin and English.

Finding #2: Both the English and Mandarin speech in noise were improved with the help of hearing aids.

Hearing impairment has been shown to interfere with patients' daily lives and communicative behaviours (Tsakiropoulou, Konstantinidis, Vital, Konstantinidou, & Kotsani, 2007). It can also affect patients' emotional and social functions. Research finding #2 indicated that both the thresholds of English and Mandarin speech in noise improved with the assistance of hearing aids. Therefore, we can conclude that hearing aids prescribed in New Zealand can improve thresholds for hearing English or Mandarin speech in noise, which is in line with Hypothesis 2.2.

The primary goal of hearing aids is to improve speech audibility while minimizing acoustic distortion (Souza, 2016). Studies have demonstrated that hearing aids can provide acoustic benefits, particularly when speech is at soft and conversational levels and background level relatively low or in quiet environments (Cox & Alexander, 1991; Kuk, Lau, Korhonen, & Crose, 2015). A recent study found that hearing aids can also enhance hearing performance in high-noise situations (where the overall sound level exceeds 80-85 dB SPL), although the performance may be compromised compared to normal conversational levels (Kuk et al., 2015). This improvement is likely attributed to the widespread use of digital signal processing (DSP) in modern hearing aids, which enhances speech-in-noise benefits. DSP enables the practical development of various algorithms (Kuk et al., 2015). For instance, hearing aids with DSP can adjust gain based on input levels, automatically reduce gain for noise signals using noise reduction functions, and utilize adaptive directional microphones to enhance spatial sound and improve the signal-to-noise ratio (Kuk et al., 2015). These advances, especially noise reduction and adaptive directional microphones, have been proven to enhance listening comfort and provide a better signal-to-noise ratio in high-noise environments (Peeters, Kuk, Lau, & Keenan, 2009).

Hearing aids also provide benefits to the quality of life of individuals with hearing impairment and reduce the hearing handicap (Chisolm et al., 2007; Kuk et al., 2015). The hearing handicap refers to the inconveniences caused by hearing impairment in someone's daily life, which can be improved with the use of hearing aids. In a MarkeTrak VIII survey conducted by Kochkin (2011) among 2,090 patients, it was estimated that approximately 88% of patients experienced a 55% improvement in their hearing handicap with recent advancements in hearing aid technology. Moreover, 90% of patients reported a significant improvement in their quality of life once their hearing handicap was reduced to 70%. Kochkin's survey also confirmed that patients experienced greater improvement in quiet situations (such as one-on-one conversations in a quiet environment) compared to noisy environments (such as small gatherings). These findings demonstrate the benefits of hearing aids in improving people's quality of life, including their ability to engage in speech conversations with others, their emotional well-being, and their participation in social activities.

Several reasons may justify why speech recognition thresholds improve with the help of hearing aids. Hearing aids utilize two technologies to enhance speech recognition in noise: directional microphones and digital noise reduction. Directional microphones utilize their "directionality" to capture sounds from a specific direction while reducing noise from other locations (Jespersen, Kirkwood, & Groth, 2021). Digital noise reduction assists hearing aids in distinguishing speech-like signals from noise-like signals and reducing unwanted noise (Bentler & Chiou, 2006). Directional microphones are commonly used to assist patients in understanding speech in noisy environments. In a study by Leeuw and Dreschler (1991), the effectiveness of hearing aids with directional microphones was measured by placing the speech source at 0º azimuth and the competing noise at 0º, 45º, 90º, 135º, and 180º azimuths. They found that the benefit of directional microphones was relatively independent of the angle of the noise and speech in a reverberant room. Leeuw and Dreschler (1991) also observed that the greatest advantage of separating loudspeakers with azimuths of 0º and 180º was in a non-reverberant environment (Leeuw & Dreschler, 1991; Sung et al., 1975). In the present research, participants were seated directly in front of the speaker in a soundproof/non-reverberant room, and noise and speech were played simultaneously. It is possible that the directional microphone may not have provided as many benefits as intended, although no quantitative measurements of such benefits were obtained in the current research.

Meanwhile, digital noise reduction is designed to improve patients' comfort and speech quality by providing less amplification to noise than to speech (UKNGC, 2018). The current research did not give significant consideration to the different brands of hearing aids and the advanced feature settings of participants' hearing aids, as studies have shown no strong connection between speech recognition in noise abilities and the choice of advanced features in hearing aids (Davidson et al., 2022). Davidson's (2022) research also found that digital noise reduction is not significantly associated with the degree of difficulty in speech-in-noise tasks. Digital noise reduction can help reduce listening effort in noisy environments (Reinhart, Zahorik, & Souza, 2020). In more challenging listening environments, such as speech in a noisy background, listening effort tends to be higher. Listeners need to exert more effort to inhibit unwanted noise signals in order to focus on speech (Reinhart et al., 2020). Therefore, digital noise reduction eases the cognitive load on listeners by assisting the auditory system in suppressing noise (Reinhart et al., 2020). As a result, listeners may experience less fatigue and allocate more cognitive resources to processing speech signals, potentially improving speech intelligibility to some extent. Since the testing materials in the present research were single words, participants may have relied more on peripheral hearing to identify the words rather than cognitive ability. Therefore, decreased listening effort was less considered in this research. However, based on finding #2, hearing aids provided significant benefits for listening to speech in noise (approximately 12 dB), suggesting that hearing aids may have helped improve the SNR by amplifying speech and filtering out noise. SNR is related to speech understanding and can impact the outcome of hearing aids (Walden et al., 2005).

The benefits of hearing aids in improving speech recognition have been demonstrated not only in English but also in Mandarin-speaking individuals (Miller, Watson, Dubno, & Leek, 2015; Zhang, Zheng, & Li, 2022). Mandarin-speaking children with severe hearing loss who were fitted with hearing aids before the age of three showed significant improvement in speech perception ability during the initial 36 months of hearing aid use (Zhang et al., 2022). These children also achieved significant improvements in perception scores (>85%), particularly in the recognition of vowels, consonants, and tones in Mandarin monosyllabic words. This finding is basically in alignment with finding #2: participants improved with hearing Mandarin speech in noise with the help of hearing aids.

Moreover, a primary function of hearing aids is to provide sound amplification in regions affected by hearing loss. This function helps maximize audibility while ensuring it remains below a level of loudness discomfort (Thrailkill, Brennan, & Jesteadt, 2019). The background noise tested in this research is falling within the range of low-intensity noises, which means the masking level is low. Considering the amplification capability of hearing aids, it is likely that participants experienced significant improvements in hearing speech in noise with the assistance of hearing aids.

6.3 Examination of finding #3

Aim 2.3: To investigate whether New Zealand prescribed hearing aids provide similar benefits to individuals in perceiving speech in noise in their first language and second language.

Hypothesis 2.3: The use of hearing aids would result in a larger improvement in word identification thresholds in noise for English compared to Mandarin.

Finding #3: The improvement of hearing aids in hearing Mandarin speech in noise was similar to hearing English speech in noise.

As documented in the literature review, the English language relies more on consonants than vowels for lexically related processes, while Mandarin relies more on vowels than consonants (Zhao et al., 2022). Consequently, English places a higher value on high-frequency sounds compared to Mandarin, as consonants are typically generated at higher frequencies than vowels. For example, high-frequency sounds such as /*s*/ and /*z*/ are important in English as they provide cues related to possession and plurality in a grammatical context (Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2004). Additionally, English consonants are lower in intensity compared to vowels, making them more difficult to detect (B. Li et al., 2015). Most cases of hearing loss affect higher frequencies. For instance, approximately one-third of individuals aged over 65 years have presbycusis (age-related hearing loss), which is characterized by bilateral high-frequency hearing loss. Hearing aids are prescribed based on individuals' hearing loss, with the aim of improving their speech intelligibility and compensating for the frequencies where hearing loss is most prominent.

Hypothesis 2.3 was based on the possibility that New Zealand-prescribed hearing aids might provide greater improvement in hearing English speech in noise compared to Mandarin speech in noise. However, this hypothesis was not supported by the finding. One possible explanation is that all participants did not exclusively have high-frequency hearing loss as proposed by the hypothesis. In fact, six of the participants had significant hearing loss in both low and high frequencies, as they had a flat hearing loss configuration. Among the other ten participants with sloping hearing loss, they also exhibited varying degrees of low-frequency hearing loss. As a result, hearing aids could potentially benefit both Mandarin speech recognition and English speech recognition to the same extent due to the complex configurations of hearing loss. Furthermore, when prescribing hearing aids, audiologists strive to ensure that the amplification matches the targets without exceeding uncomfortable levels in the areas of hearing loss. Sometimes, even if the hearing aids provide sufficient audibility in the regions of hearing loss, as indicated by aided audibility, the patient's psychological perception may not align with that (Weinstein, 1997). Conversely, even if the hearing aids only provide a small amount of audibility, the perceived handicap or disability may be significantly reduced (Weinstein, 1997). Thus, there can be a potential mismatch between the objectively measured outcomes and the patient's subjective perception. Therefore, after wearing the hearing aids, audiologists also inquire about the patients' subjective perceptions of the sounds. Some patients may perceive the sound as echoey, prompting the audiologist to reduce the amplification of high-frequency sounds. The final prescription of amplification is not solely based on the targets but also takes into account the patients' personal experiences. Thus, it is challenging to conclude that participants are only receiving the high-frequency amplification they require based on their hearing loss. Consequently, the improvement in thresholds with the help of hearing aids is not fixed as initially anticipated. This may explain why people experienced similar improvements in hearing Mandarin and English speech in noise, contrary to the initial hypothesis.

Native listeners and non-native listeners are both adversely affected by increasing noise when hearing speech in noise (Cutler et al., 2004), but non-native listeners tend to be more affected than native listeners. The impact of noise appears to be comparable between non-native speakers and native speakers, as non-native speakers' phoneme identification scores are approximately 80% of those of native speakers across all SNRs studied (Cutler et al., 2004). Similar improvements were observed in hearing Mandarin and English speech in noise with the use of hearing aids. Hearing aids incorporate technologies that support individuals with sensorineural hearing loss in hearing speech in noise, effectively improving the SNR. As the SNR improves, the ability to hear speech in noise also improves. This may explain why the improvements in hearing speech in noise with the assistance of hearing aids were similar for both Mandarin and English.

Individuals with steep high-frequency sensorineural hearing loss and normal low-frequency thresholds tend to have poorer low-frequency hearing compared to those with normal hearing (B. Li et al., 2015). Research has shown that they exhibit poorer than normal sentence recognition specifically in the low-frequency regions, despite having clinically normal thresholds (B. Li et al., 2015). This could be attributed to their difficulty in perceiving temporal fine structure cues, which are important for speech recognition in noise (B. Li et al., 2015). Therefore, if all the participants in the present research had solely high-frequency hearing loss, their speech perception would not only be affected in the high-frequency areas, which are more critical for English, but their low-frequency hearing, crucial for Mandarin, could also be impacted. Given that the participants have both high-frequency and low-frequency hearing loss, it becomes challenging to determine which language would be more affected in terms of speech perception. Consequently, when wearing hearing aids, the improvements in Mandarin and English speech perception may be similar.

Nevertheless, this finding does not imply that we should disregard the Mandarin speech in noise test for individuals whose first language is Mandarin in clinical practice. While a group of 19 participants in this study showed similar improvements in hearing Mandarin speech in noise and English speech in noise, it is uncertain whether the benefits are consistent for each of the individuals. In clinical practice, audiologists must still exercise clinical judgment based on each patient's specific condition.

6.4 Secondary analyses

Summary of secondary analysis findings:

1) The configuration of hearing loss does not influence the threshold of Mandarin or English speech identification, regardless of whether the participants are using hearing aids or not.
2) Overall (regardless of language or hearing aid use), participants with sloping losses had slightly better thresholds compared to those with flat losses, although the difference was marginally significant.
3) There is a moderate correlation between hearing aids benefits in English and Mandarin, although the improvement resulting from hearing aids is somewhat dependent on the language being spoken.

The first finding obtained through secondary analyses pertains to the relationship between language, hearing aid use, and hearing loss configuration, and found there is no interactions among the three variables. In this study, patients might receive the same amount of benefits from their hearing aids to hear their first and second languages. However, since Mandarin is their first language, their perceived disability may be more reduced when hearing Mandarin. Conversely, some patients may have more high-frequency hearing loss, and therefore, when they receive more amplification in the high frequencies, their hearing aids provide more benefit for hearing English. Consequently, the results of the tests demonstrated that hearing loss configuration did not influence the language pattern or the use of hearing aids.

Then, the secondary analysis revealed an overall trend indicating that individuals with flatter hearing losses tended to perform more poorly in both languages, although the effect was only marginally significant. This trend could be attributed to the degree and configurations of the participants' hearing loss. Most participants with sloping hearing loss experienced age-related hearing loss, while those with flat hearing loss had various etiologies. Individuals with sloping hearing loss often retain some low-frequency hearing, which aids their speech perception. However, individuals with flat hearing loss do not have any frequency regions to rely on, which may explain their poorer speech perception thresholds. Interestingly, this finding contradicts the results reported by Hornsby et al (2011), which concluded that benefit from speech information in a given frequency region generally decreased as degree of hearing loss in that frequency region increased.

Some research has indicated limited benefits from speech amplification for individuals with high-frequency hearing loss, particularly when the high-frequency (≥3000-4000Hz) hearing loss exceeds 55-80 dB HL (Amos & Humes, 2007). Interestingly, this limited benefit from speech amplification in the high-frequency range appears to be similar for both high-frequency sloping hearing loss and flat hearing loss (Hornsby & Ricketts, 2006). In the study conducted by Hornsby & Ricketts (2006), the participants had controlled hearing loss degrees, and the two groups (sloping high-frequency hearing loss vs. flat hearing loss) exhibited similar high-frequency hearing levels but significantly different low-frequency hearing levels. It is also noted that participants with high-frequency sloping hearing loss exhibited reduced ability to utilize high-frequency speech information but near-normal utilization of low-frequency information, while participants with flat hearing loss experienced reduced utility of speech information across the entire frequency range (Hornsby & Ricketts, 2006).

This finding suggests that the ability to extract information from amplified speech components is similar at both low and high frequencies, assuming the hearing loss is similar across all frequencies. In other words, the utility of amplified high-frequency information is not additionally affected by the configuration of the hearing loss. Hornsby & Ricketts' (2006) findings are potentially aligned with the present research, which demonstrates that participants with sloping hearing loss perform better in speech identification compared to participants with flat hearing loss. This could be because participants with sloping hearing loss can benefit from the low-frequency speech information and thereby improve their speech perception.

Thirdly, the benefit of hearing aids in English and Mandarin showed a moderate correlation, indicating that the improvement provided by hearing aids is generally similar in both languages but can also be influenced by the individual's language preferences. This finding is consistent with the main finding #3, which demonstrated that hearing aids yielded similar improvements for understanding Mandarin speech in noise and English speech in noise. It suggests that the assessment of hearing aid benefits should take into account the individual's specific hearing condition and language needs.

There are various factors that can impact speech recognition thresholds, beyond just the configuration of hearing loss. The degree of hearing loss is a significant factor that influences an individual's speech recognition performance (Hornsby et al., 2011). As the degree of hearing loss increases, speech recognition performance generally deteriorates (Hornsby et al., 2011). However, with the assistance of hearing aids, speech recognition in noise improves for both languages. Nonetheless, it is important to note that individual participants may experience varying degrees of benefit in English speech recognition in noise compared to Mandarin speech recognition in noise. This discrepancy could be attributed to various factors, such as the degree of hearing loss and the familiarity or convenience of the first language. It is challenging to determine the exact extent of benefit individuals receive when listening to their first language in noise compared to their second language. To address this factor, future studies should examine participants who speak English as their first language and Mandarin as their second language and compare their results.

Additionally, it is worth noting that background noise can also impact the utilization of amplified high-frequency speech information (Turner & Henry, 2002). Although the current study controlled the background noise to 43 dBA, further investigation is needed to explore the potential interference of such noise with high-frequency amplification in the future.

6.5 Examination of incidental findings

There was a correlation observed between the benefits of hearing aids in English and Mandarin, indicating that individuals who experienced greater improvement in hearing English also tended to have greater improvement in hearing Mandarin. However, there was an exceptional case involving Participant X, who exhibited a significant (23 dB) benefit in hearing English with the assistance of hearing aids but showed no improvement in hearing Mandarin. The audiogram of Participant X (Figure 9) revealed a precipitous slope from low frequency to high frequency. In the range of 250 Hz to 1.5 kHz, the hearing loss was normal to slight, but from 2 kHz to 8 kHz, there was precipitously sloping from mild hearing loss to profound hearing loss bilaterally.

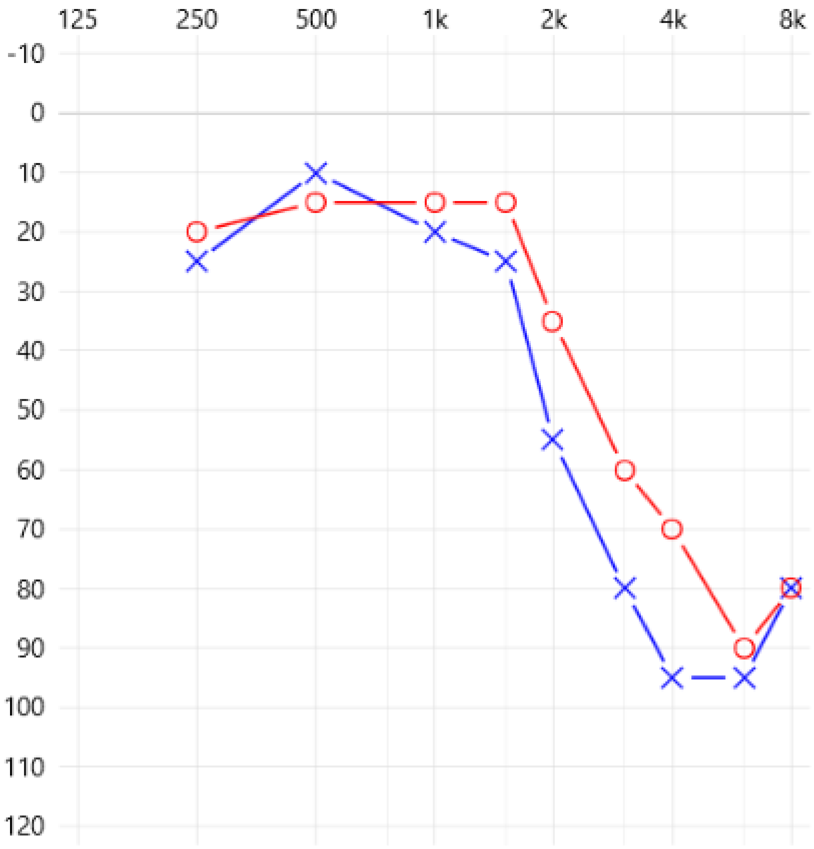

Figure 9: Patient X's audiogram

This participant appeared to heavily rely on low frequencies when hearing Mandarin. Even without wearing hearing aids, his threshold for Mandarin identification in noise at 48 dBA indicated that he could understand normal conversations well. Therefore, he did not heavily rely on hearing aids to comprehend conversational speech. The test results further confirmed that this participant received no benefit from hearing aids when listening to Mandarin speech in noise. However, he required the ability to hear high frequencies when listening to English speech and showed a significant improvement in thresholds after wearing hearing aids. This is likely because English is his second language. Consequently, in the presence of background noise, he struggled to hear English without hearing aids (threshold at 81 dBA). This higher threshold than expected could be due to fatigue experienced by the participant, despite the student researcher suggesting breaks in between. After wearing hearing aids, the participant's threshold for English identification improved significantly. It is possible that the hearing aids effectively alleviated the participant's hearing strain, leading to increased confidence and easier speech comprehension, particularly in his second language (English). It is also likely that the hearing aids helped amplify the high frequencies that are more crucial for the English language. Based on the participant's personal experience, he did not perceive the need to wear hearing aids in a Mandarin-speaking environment, but he indeed required hearing aids in an English-speaking environment.

6.6 Strengths and limitations

A main strength of this research is the development of Mandarin and English word sets for speech tests in noise. These word sets were carefully developed and calibrated, providing stimuli with balanced sound levels. Currently, there is a lack of commonly used Mandarin speech test material available for free use in New Zealand. The creation of a set of Mandarin words with a comparable range of sound levels to the commonly used CVC English word lists can have clinical benefits for Mandarin speakers. For example, these Mandarin word sets can be used to assess how Mandarin-speaking individuals perceive speech in noise, providing them with direct insights into their abilities. Additionally, the Mandarin word sets can be utilized to evaluate the benefits of hearing aids, similar to the adaptive testing procedure used in this research. The adaptive testing procedure was employed for both Mandarin speech in noise and English speech in noise, enabling the determination of the 50% correctness threshold for both languages and facilitating comparisons between them. It also simplifies the testing procedures for future clinicians. This research explores the impact of healthcare (hearing aid benefits) on a minority ethnic group—Chinese people in New Zealand. New Zealand values cultural diversity, and the findings of this research could lay the groundwork for future healthcare policies aimed at minority ethnic groups, such as the establishment of language-specific hearing tests for individuals whose first language is not English. This could potentially encourage people to seek hearing care services.

The present research utilized words instead of sentences for testing purposes in order to minimize participants' cognitive processing efforts. Current clinically used speech in noise tests, such as HINT (Hearing-in-Noise Test) or QuickSin, typically involve sentence-based testing, which encompasses both higher cognitive processing and peripheral hearing abilities. Considering the varying language proficiency levels of the participants in this research, employing words instead of sentences as testing materials effectively mitigates the cognitive impact of language ability. Testing with words enables a focus on peripheral hearing levels and provides insights into how individuals perceive speech. Furthermore, testing words is easy to implement in clinical practice and involves fewer linguistic factors, making it suitable for bilingual speakers.

Another strength of this research is the enrolment of bilingual speakers (Mandarin and English) wearing New Zealand-prescribed hearing aids. Despite New Zealand being a culturally diverse country, the Chinese community is relatively small in size. Therefore, recruiting individuals who wear hearing aids from this specific group posed a challenge. To overcome this, the student researcher employed various strategies. They visited local communities such as churches and local markets to distribute advertisement flyers, utilized personal networks to raise awareness about the research, and provided additional support for transportation by offering pick-up and drop-off assistance to participants who faced inconveniences with public transportation. These efforts were undertaken to ensure a sufficient and diverse participant pool for the study.

A limitation of this study was the absence of a group of hearing aid users who have English as their first language and Mandarin as their second language. We observed that native

Mandarin speakers showed similar improvements in hearing Mandarin speech in noise and English speech in noise when using hearing aids. However, it remains uncertain whether this similarity accurately reflects the findings or if the amount of improvement would have been greater for the native language. This uncertainty arises due to the tonal nature of Mandarin and its reliance on low frequencies, where most individuals typically do not experience hearing loss. To establish more certainty regarding the extent of benefit provided by New Zealand-prescribed hearing aids for bilingual individuals (Mandarin and English speakers), it would be valuable to include a group of native English speakers to assess whether consistent results are obtained.

Due to time limitations, we were unable to conduct pure-tone audiometry prior to the speech-in-noise test. Therefore, information regarding participants' hearing loss was obtained from their hearing aids, which recorded the results of their most recent hearing check. It is important to note that participants' hearing might have potentially changed since their last assessment. However, none of the participants reported any issues with the functioning of their hearing aids, indicating that their prescribed devices were still effectively addressing their hearing loss.

Additionally, it is important to note that the sample frame of this research predominantly consisted of participants from the city of Auckland, New Zealand. To ensure a more comprehensive representation of the population, future studies could include participants from various regions across New Zealand. Furthermore, expanding the sample size would enhance the statistical power and generalizability of the findings.

6.7 Clinical implications

The findings of this study support the notion that New Zealand prescribed hearing aids provide similar benefits for hearing Mandarin speech in noise as they do for hearing English speech in noise. Currently, clinical protocols do not typically include a speech in noise test as part of the hearing aid prescription process for patients who report difficulties in understanding speech in noise, despite the fact that such a test can accurately assess their speech perception abilities in challenging listening environments (Davidson et al., 2022). The results of this study highlight the importance of incorporating speech in noise testing in clinical evaluations, as it directly informs clinicians about the extent to which hearing aids can improve speech recognition in noise.

When considering the inclusion of speech in noise testing for bilingual speakers, such as those who speak Mandarin as their first language, it is necessary to evaluate whether it is essential to include their first language in the testing protocol (e.g., Mandarin disyllabic words in noise test). In reality, individuals' first language may not be English, and they may prefer to use their first language, which may have a different linguistic structure than English. The current research demonstrated that the benefits of hearing aids were similar for both first language (Mandarin) and second language (English) speech recognition in noise. Therefore, it is plausible to utilize English speech in noise tests to assess the benefits of hearing aids for patients who primarily listen to their first language (e.g., Mandarin speech in noise). However, this finding does not exclude the use of Mandarin speech in noise tests to evaluate individuals who speak Mandarin as their first language. Further analysis and future research are warranted to examine how hearing aids support individuals who speak English as their first language and Mandarin as their second language, providing more conclusive evidence in this regard.

CHAPTER 7. CONCLUSION

Considering the absence of any prior study addressing the hearing loss among the Chinese community in New Zealand and the potential benefits they might receive from prescribed hearing aids, this research aimed to fill that gap. Mandarin and English speech-in-noise tests were developed and administered to a sample of 19 bilingual speakers, with Mandarin as their first language and English as their second language. The primary aim was to investigate the benefits of hearing aids.

The results of the tests revealed that hearing aids prescribed in New Zealand can improve participants' ability to hear speech in noisy environments. Furthermore, the benefits observed for perceiving Mandarin speech in noise were similar to those for English speech in noise. These findings have significant implications for audiology practices in New Zealand, suggesting that English speech-in-noise tests could potentially be utilized to assess the benefits of hearing aids in bilingual speakers whose first language is Mandarin. Nevertheless, a personalized hearing aids prescription (including first language-based speech-in-noise test) is preferred for the individuals, considering their first language and other preferences.

Further studies should be conducted in the future to validate the main findings of this research on a larger scale with more diverse samples. Testing bilingual speakers who have English as their first language and Mandarin as their second language would further contribute to the well-being of a larger population in New Zealand.

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APPENDIX

Appendix 1. Consent Form

Consent form

This form will be held for six years

知情同意书

此知情同意书将会被保存 6 年

Research title: Investigation of the benefit from New Zealand prescribed hearing aids for bilingual speakers in Mandarin and English speech in noise tests

研究标题：探讨在新西兰验配的助听器对于中英双语人士在噪声背景下对言语听力的作用

Student investigator: Daisy Yu Supervisor: David Welch Co-supervisor: Jiana Wu

研究人员：Daisy Yu 导师：David Welch 副导师：Jiana Wu

I have read the 'Participant Information Sheet' and have understood the nature of the research and why I have been selected. I have had the opportunity to ask the investigators questions and have had them answered to my satisfaction.

我已阅读'参与者须知'并了解了本研究的性质以及为何我适合参加。我有向研究员询问问题的机会并且他们的回答让我很满意。

- I agree to take part in this research.

  我同意参与此项研究

- I am over 18 years old, have hearing loss, and wear New Zealand prescribed hearing aids.

  我超过 18 岁，有听力损失并且佩戴在新西兰验配的助听器

- I understand that during the experiment, I may need to cooperate with the researchers to turn my hearing aids on and off.

  我了解在实验过程中，可能会需要配合研究人员开关或者摘戴我的助听器。

- I can speak both Mandarin and English.

  我会讲中文普通话和英语

- I understand that I will have a hearing appointment at the University of Auckland, Grafton campus Audiology clinic and that the hearing tests will take no more than 120 minutes.

  我了解我将会在奥克兰大学，Grafton 校区，听力实验室进行 120 分钟的听力测试。

- I understand there will be four sessions during the hearing test. The Mandarin speech in noise test with hearing aids off, English speech in noise test with hearing aids off, Mandarin speech in noise test with hearing aids on, and English speech in noise test with hearing aids on.

  我了解此听力实验包含四部分，普通话噪声中言语听力测试（无助听器辅助），英语噪声中言语听力测试（无助听器辅助），普通话噪声中言语听力测试（有助听器辅助），英语噪声中言语听力测试（有助听器辅助）。

- I have been given sufficient time to consider whether or not to participate in this study.

  我被给予足够时间考虑是否参与此次实验研究。

- I am satisfied with the answers that I have been given regarding the study, and I have a copy of the ‘Participant Information Sheet’ and ‘Consent Form’.

  我对我已获得的与本研究相关的答案信息感到满意，我已获得一份“参与者须知”以及“知情同意书”的副本。

- I understand that participating in this study is voluntary (based on my choice) and I can withdraw from the study at any time.

  我明白参与此次实验研究属自愿行为，并可以在任何时候终止参与实验研究。

- I understand that if I withdraw from the study before or during the hearing test the researcher will stop collecting information from me. Which means my hearing test will be terminated immediately.

我了解如果我在听力测试之前或之中决定撤出本实验研究，研究人员将停止收集我的信息，我的听力测试将被终止。

- I understand that after the data collection (hearing tests) is completed, my data will be combined with the data from other participants. The researchers will no longer be able to identify which data is mine, so, therefore, I will no longer be able to withdraw my data or withdraw from the study.

  我了解在数据收集（听力测试）完成之后，我的实验信息将会与其他参与者的数据一起被匿名保存。研究人员将无法分辨哪些数据是我的，所以我将无法提取自己的数据或取消我的实验结果。

- I understand that my participation in this study is confidential and that materials that can identify me will not be used in any reports of this study.

  我了解此次实验研究采用参与者匿名信息，并且实验报告中不包含我的任何身份信息。

- I understand that the ‘Consent form’ will be locked away at the University of Auckland Department of Audiology. After six years, it will be destroyed. The data we collected for this research are named with non-identifiable numbers, participants’ identifiable information such as name or date of birth will not be included. That collective data will be kept in an electronic file and stored indefinitely (for potential future analysis) in a password protected database.
  我了解‘知情同意书’会被锁存在奥克兰大学听力部门6年，之后会被销毁。我们收集到的数据将会以匿名的数字命名，参与者的身份信息例如姓名和出生日期将不会被包含在收集到的数据内。收集到的数据将会被无限期（以备将来所需）保存在加密保护的的电脑文件内。

- I know who to contact if I have questions about the study.
  如果我有与本次实验研究相关的任何问题，我知道该与谁取得联系。

- I know that after my participation, I will receive a $30 Countdown supermarket voucher as a ‘Thank you’ voucher.

我知道在我参与实验完成后，将获得一张价值$30 的 Countdown 超市代金券，作为对我的感谢。

- I would like to receive a summary of the study findings via email once the research is completed. Please circle “yes” if you would like to.
  我愿意在本研究结束以后通过邮件获得一份本实验最终研究结果的简单介绍，如果需要的话,请您圈上“Yes（是）”。

Yes（是）　　　　No（否）

If yes, please write your email address here/如果您选择 ‘是’，请将您的电子邮箱留下：

____

Declaration by participant/参与者声明:

I hereby consent to take part in this study.

我同意参与此次实验研究。

Participant’s name/参与者姓名:

____

Signature/签名:

____

Date/日期:

____

Approved by the Auckland Health Research Ethics Committee on [9/Jan/23] for three years. Reference number [AH25367]”.

由奥克兰健康研究伦理委员会于【2023 年 1 月 9 日】批准，获批期限为三年。参考号为【AH25367】。

Appendix 2. Participant's Information Sheet (English)

Participant Information Sheet

Department of Audiology

Faculty of Medical and Health Sciences

22-30 Park Avenue, Grafton, Auckland 1023

Research title: Investigation of the benefit from New Zealand prescribed hearing aids for bilingual speakers in Mandarin and English speech in noise tests

Study site: University of Auckland Audiology laboratory

Student investigator: Daisy Yu Supervisor: David Welch Co-supervisor: Jiana Wu

Contact details: myu095@aucklanduni.ac.nz

This research project is conducted for a student researcher's master thesis.

You are invited to take part in a study about the effectiveness of hearing aids for bilingual speakers when listening to speech in background noise. Whether or not you take part is your choice. If you don't want to take part, you don't have to give a reason. If you do want to take part now, but change your mind later, you can pull out of the study at any time.

This Participant Information Sheet will help you decide if you would like to take part. It sets out why we are doing the study, what your participation would involve, what the benefits and risks to you might be, and what would happen after the study ends. We will go through this information with you and answer any questions you may have. You do not have to decide today whether you will participate in this study. Before you decide you may want to talk about the study with other people, such as family or friends. Please feel free to do this.

If you agree to take part in this study, you will be asked to sign the Consent Form. You will be given a copy of the Participant Information Sheet to keep.

What is the purpose of this study?

This study is investigating how New Zealand prescribed hearing aids benefit bilingual speakers with Mandarin as the first language and English as the second language in hearing Mandarin or English speech in noise.

Who will take part in this study?

We are looking for individuals, over 18 years old, who are bilingual speakers (with Mandarin as the first language and English as the second language), who have hearing loss and wear hearing aids that were fitted by an audiologist in New Zealand.

What will participants in the study be asked to do?

We need to recruit around 20 participants.

Each experiment for individual participants takes about 120 minutes. Each experiment includes 4 sessions: Mandarin speech in noise with hearing aids off, English speech in noise with hearing aids off, Mandarin speech in noise with hearing aids on, English speech in noise with hearing aids on. The experiments will happen in the University of Auckland audiology laboratory.

None of them will be any louder than you would normally hear in your daily life. We will hear Mandarin and English words spoken in the background noise, and we will ask you to repeat whatever you hear. We will play a constant level of noise and varied levels of speech, but ask you to carry out these listening tasks with or without your hearing aids because we are interested to know how much your hearing aids help you hear Mandarin or English speech in noise.

If you have any cultural concerns, you can choose to discuss them with your families and friends first. We are also happy to discuss your cultural concerns with you.

What are the possible risks of this study?

- There is no side effect of these study research toward participants' health
- The hearing test will take about 120 minutes in total, so you might possibly feel a bit tired. To help avoid that, we will let you take breaks during the test
- We will take great care that none of the information about your hearing is ever published in any way that could identify you, and to ensure this is the case, we will not record your name when we save the information that we collected about you.

What are the possible benefits of the study?

This study intends to compare the benefit of New Zealand prescribed hearing aids for bilingual speakers (with Mandarin as the first language and English as the second language) when hearing their first language in noise to hear their second language in noise. This study may have implications for future hearing aids prescription for bilingual speakers.

Voucher to say Thank-you

By taking part in this research, participants will contribute to the development of hearing health research. A 'Thank you' voucher with a value of $30 from a supermarket (e.g. Countdown) will be given to each participant.

What will happen to my information?

Your data will be recorded in a computer file in an unidentified form. These data will form the basis of this research project.

Identifiable information

Identifiable information is any data that could identify you (e.g. your name). To make sure that you could not possibly be identified, information that could identify you will not be included in the data or any report generated by the researcher.

Security and storage of your information

Your consent form will be locked away at the UoA Audiology section for 6 years, then will be destroyed. Your research data will be entered into an electronic file and stored indefinitely (for potential future analysis) on password protected computers.

Rights to withdraw your information

You may withdraw your consent for the collection and use of your information at any time up till the end of the data collection session, by informing the researcher.

If you withdraw your consent, your study participation will end, and we will stop collecting information from you.

After your data collection session is completed, your data will be combined with the data from other participants in an unidentified form. We will not know which is your data, so it will no longer be possible to withdraw your data after that point.

Can I find out the results of the study?

If you would like to receive a summary of the final research findings, we will send them to you via email. The analysis of the data will be presented in the researcher's thesis, you can also have a copy of the thesis if you are interested.

Who do I contact for more information if I have a concern?

If you have any questions, concerns or complaints about the study at any stage, you can contact:

Daisy Yu via email: myu095@aucklanduni.ac.nz

Dr David Welch via email: d.welch@auckland.ac.nz

Or Dr Grant Searchfield (Head of Section Audiology) via email:
g.searchfield@auckland.ac.nz

For concerns of an ethical nature, you can contact the Chair of the Auckland Health Research Ethics Committee at ahrec@auckland.ac.nz or at 373 7599 ext. 83711, or at Auckland Health Research Ethics Committee, The University of Auckland, Private Bag 92019, Auckland 1142.

Approved by the Auckland Health Research Ethics Committee on [9/Jan/2023] for three years. Reference number AH25367.

Appendix 3. Participant’s Information Sheet (Chinese)

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

MEDICAL AND
HEALTH SCIENCES

志愿者须知

奥克兰大学听力科

医学与健康科学部

22-30 Park Avenue, Grafton, Auckland 1023

研究标题：在新西兰验配的助听器对于中英双语人士在噪声中言语听力的作用

实验地点：奥克兰大学听力科实验室

研究人员：Daisy Yu　　导师：David Welch　　副导师：Jiana Wu

联系方式：myu095@aucklanduni.ac.nz

本研究项目归属于学生研究员硕士论文。

您被邀请参与实验研究助听器对于中英文双语人士在噪声中言语听力的作用。参与或不参与本实验研究均是您个人的自由选择。如您选择不参与，则无需给出任何理由。如您当下选择参与，在实验研究过程中若有意愿更改，您也可以选择随时退出研究。

此“志愿者须知“能帮您了解并决定是否参与本实验研究。其内容包括：实验研究原因，与您相关的实验内容，风险，益处以及研究结束后会发生什么。所有信息公开透明，并且您可以随时进行提问。您可以思量斟酌，或与家人朋友商议是否参与本实验研究。如果您同意参加本次研究，您将需要签署同意书。并获得一份“志愿者须知“的副本保留。

本次实验研究的目的有哪些?

本次实验旨在研究在新西兰验配的的助听器对于中英文双语人士（中文普通话是第一语言，英语是第二语言）在噪声中言语听力的作用

谁可以参与本次实验研究?

我们正在招募中英文双语人士（中文普通话是第一语言，英语是第二语言），18岁以上，有听力损失并且佩戴由新西兰听力师验配的助听器。

研究参与者将需要做什么?

我们需要招募大约20名志愿者。听力测试时长为120分钟。测试内容由四个部分组成：普通话噪声中言语听力（无助听器辅助），英语噪声中言语听力（无助听器辅助），普通话噪声中言语听力（有助听器辅助），英语噪声中言语听力（有助听器辅助）。听力测试地点为奥克兰大学听力科实验室。

您将会听到中英文噪声中言语单词，您只需重复所听到的每个词。我们将播放恒定水平的噪音， 测试词的声音大小会有变化，但不会超过正常言语响度。我们将会分别在您佩戴助听器及不佩戴的情况下对您进行听力测试，来了解您的助听器在多大程度上帮助您在噪音中听到中文普通话或英语。

如果参与者有任何文化上的顾虑，您可以选择先和家人朋友们讨论。我们也很乐于和您讨论您的文化上的顾虑。

实验可能的风险有哪些?

- 实验本身不会对参与者的身体健康造成任何损伤
- 整个听力测试时长可达120分钟，所以结束时您可能会觉得有些疲劳。为了缓解疲劳，听力测试过程中我们会提供休息时间
- 您的个人信息都会被匿名，以保证您的个人信息安全

本次实验研究的益处有哪些？

本实验旨在研究新西兰验配的助听器对中英文双语人士(中文普通话为第一语言，英语为第二语言)在噪声中言语听力的作用。实验结果或将作用于未来双语者的助听器的验配。

参与实验的奖励

通过参与这项研究，您将为听力健康研究的发展做出贡献。每位参与本次实验研究的志愿者将能获得$30 Countdown 代金券，作为我们的感谢。

志愿者测试结果将会被怎样处理？

您的测试结果将会以匿名形式保存于电脑文档中，作为数据构成这个研究项目的基础。

身份信息

可识别信息是任何可以识别您的信息(例如：姓名)。为了确保您的个人身份信息安全， 您的可识别信息将不会出现在实验数据或任何研究报告中。

信息安全及储存

您的知情同意书将会被保存于奥克兰大学听力科 6 年，之后会被销毁。您的实验结果会被无限期（以备将来的可能研究）保存于加密电脑文档中。

撤出实验

在您的听力测试开始前及测试中，您可以通过通知研究人员，随时无条件撤出本实验研究。

在您决定撤出本实验研究后，您的研究参与将终止，您的听力测试也将即刻终止。

在您的听力测试结束之后，您的实验信息将会与其他参与者的数据一起被匿名保存。届时如果您决定撤出本实验研究，我们将不哪些法分辨哪些是您的数据，所以将无法取消您的测试结果。

我能知道这个研究的结果吗?

如您希望收到最终研究结果的摘要，我们将通过电子邮件发送给您。数据分析内容会以研究员的硕士论文呈现，如您感兴趣，我们可提供研究员的硕士论文副本给您。

如有疑问，我应该联系谁获取更多信息

如有任何疑问或兴趣，请联系研究员 Daisy Yu。邮箱: myu095@aucklanduni.ac.nz

或研究员导师，教授 David Welch。邮箱: d.welch@auckland.ac.nz

或教授 Grant Searchfield（部门主管）。邮箱: g.searchfield@auckland.ac.nz

如您对伦理问题有任何疑问，可以联系奥克兰健康研究伦理委员会主席通过邮箱: ahrec@auckland.ac.nz，或电话: 373 7599 接 83711， 或奥克兰健康研究伦理委员会，奥克兰大学，专用邮袋 92019，奥克兰 1142。

由奥克兰健康研究道德委员员于 2023 年 1 月 9 日批准，获批期限为三年，参考号码为 AH25367。

Appendix 4. Research Advertisement

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

MEDICAL AND HEALTH SCIENCES

Research Title: Investigation of the benefit of New Zealand-prescribed hearing aids for bilingual speakers in Mandarin and English speech in noise tests

研究标题：探讨在新西兰验配的助听器对于中英双语人士在噪声背景下对言语听力的作用

WE NEED VOLUNTEERS FOR AN INTERESTING STUDY!

寻找会说中-英文双语的志愿者!

I will test your hearing of Mandarin and English speech in noise. The testing procedure takes up to 2 hours in total. The study result will have an implication for future hearing aid prescriptions for bilingual speakers.

我将会测试您在噪声中的中文言语听力以及英文言语听力。测试时长可达 2 小时。研究成果或将作用于将来的助听器选择与配试。

Eligibility criteria/参与条件:

To be eligible for this study, you must/ 参与本研究，您须是：

- Be bilingual speakers, Mandarin as the first language and English as the second language/中英文双语人士，第一语言是中文，第二语言是英文
- Be aged over 18/年龄超过 18 岁
- Have hearing loss and wear hearing aids/有听力损失并佩戴助听器

REIMBURSEMENT/ 参与奖励

- **$30 Countdown supermarket voucher/ $30 Countdown 超市代金券**

I will be undertaking this project as part of my Master of Audiology degree at the University of Auckland. 本研究是我在奥克兰大学听力学的硕士研究项目。

For further information and to take part in the study, please feel free to contact: **Daisy Yu** **Email: myu095@aucklanduni.ac.nz** **Mobil: 0224509134**

如需了解更多信息或有意愿参与本研究，请联系：

Daisy Yu **邮箱：myu095@aucklanduni.ac.nz** **电话：0224509134**

"Approved by the Auckland Health Research Ethics Committee on [9/Jan/23] for three years. Reference number [AH25367]". 由奥克兰健康研究伦理委员会于【2023 年 1 月 9 日】批准，获批期限为三年。参考号为【AH25367】。

Appendix 5. English CVC Words

CVC Word List

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

MEDICAL AND HEALTH SCIENCES

Name: ______________________ Date: __________ Time: ________

DOB: ______________ Age: ________ Clinician: ____________________ ☐MNZAS

Student/Intern Audiologist: ______________________________

List 1	**List 2**	**List 3**	**List 4**
Ear *Level* *Masking*	*Ear* *Level* *Masking*	*Ear* *Level* *Masking*	*Ear* *Level* *Masking*
pass	hall	pies	boss
rule	come	mock	sip
cause	bag	room	pal
time	rose	dad	coat
log	suit	loan	rod
sick	made	beg	moon
mean	like	tell	hem
bed	peace	keep	take
hope	dip	hiss	league
date	ten	sought	dies
Score	**Score**	**Score**	**Score**
List 5	**List 6**	**List 7**	**List 8**
Ear *Level* *Masking*	*Ear* *Level* *Masking*	*Ear* *Level* *Masking*	*Ear* *Level* *Masking*
time	make	seal	hide
caught	laws	dawn	tame
beg	rice	boom	rule
rid	bell	hog	cause
loon	tote	toes	big
mop	cod	mid	sass
doze	ham	cat	pope
says	deep	like	don
pack	pig	pep	meek
heel	soon	race	let
Score	**Score**	**Score**	**Score**
List 9	**List 10**	**List 11**	**List 12**
Ear *Level* *Masking*	*Ear* *Level* *Masking*	*Ear* *Level* *Masking*	*Ear* *Level* *Masking*
call	lean	lice	dike
buys	hag	mall	ball
same	bed	tomb	mace
miss	sews	bag	rig
rot	cop	soap	lose
hoop	root	rake	sop
load	pick	pen	comb
peck	maim	keys	ten
tag	toss	hid	pad
dean	dial	dot	heat
Score	**Score**	**Score**	**Score**

Appendix 6. Mandarin Disyllabic Words

普通话双音节词表

双音节词表　表一

序号	测试词	反应	得分	序号	测试词	反应	得分	序号	测试词	反应	得分
1	没有 méi yǒu			18	负责 fù zé			35	树叶 shù yè		
2	现在 xiàn zài			19	地点 dì diǎn			36	大豆 dà dòu		
3	同志 tóng zhì			20	红马 hóng mǎ			37	牛奶 niú nǎi		
4	今天 jīn tiān			21	喜剧 xǐ jù			38	热心 rè xīn		
5	作者 zuò zhě			22	躲藏 duǒ cáng			39	客观 kè guān		
6	思想 sī xiǎng			23	鸡蛋 jī dàn			40	书桌 shū zhuō		
7	奖励 jiǎng lì			24	歌曲 gē qǔ			41	中等 zhōng děng		
8	汽车 qì chē			25	要求 yā qiú			42	警卫 jǐng wèi		
9	德国 dé guó			26	爱护 ài hù			43	特征 tè zhēng		
10	能够 néng gòu			27	班长 bān zhǎng			44	水稻 shuǐ dào		
11	服务 fú wù			28	拔河 bá hé			45	月票 yuè piào		
12	队员 duì yuán			29	波浪 bō làng			46	神秘 shén mì		
13	得意 dé yì			30	日记 rì jì			47	公里 gōng lǐ		
14	本身 běn shēn			31	展示 zhǎn shì			48	查询 chá xún		
15	快乐 kuài lè			32	牙齿 yá chǐ			49	很多 hěn duō		
16	报社 bào shè			33	铁路 tiě lù			50	坚硬 jiān yìng		
17	老师 ǎo shī			34	文明 wén míng						

双音节词表 表二

序号	测试词	反应	得分	序号	测试词	反应	得分	序号	测试词	反应	得分
1	妇女 fù nǚ			18	兄弟 xiōng dì			35	办法 bàn fǎ		
2	研究 yán jiū			19	美术 měi shù			36	规则 guī zé		
3	世界 shì jiè			20	科学 kē xué			37	山洞 shān dòng		
4	公民 gōng mín			21	特长 tè cháng			38	相对 xiāng duì		
5	建设 jiàn shè			22	兰花 lán huā			39	娱乐 yú lè		
6	斗争 dòu zhēng			23	报纸 bào zhǐ			40	牙膏 yá gāo		
7	营业 yíng yè			24	同意 tóng yì			41	忘记 wàng jì		
8	群众 qún zhòng			25	道理 dào lǐ			42	等待 děng dài		
9	苹果 píng guǒ			26	个人 gè rén			43	资本 zī běn		
10	恩德 ēn dé			27	救火 jiù huǒ			44	水银 shuǐ yín		
11	小说 xiǎo shuō			28	象棋 xiàng qí			45	沙漠 shā mò		
12	或者 huò zhě			29	速度 sù dù			46	帮助 bāng zhù		
13	自然 zì rán			30	迷路 mí lù			47	大姐 dà jiě		
14	歌舞 gē wǔ			31	可爱 kě ài			48	遮挡 zhē dǎng		
15	志愿 zhì yuàn			32	电车 diàn chē			49	天鹅 tiān é		
16	青菜 qīng cài			33	迟缓 chí huǎn			50	怒吼 nù hǒu		
17	发表 fā biǎo			34	立即 lì jí						