Development of a Māori Language Version of the New Zealand Hearing Screening Test

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Abstract

Hearing loss has a prevalence of 10.3% in New Zealand, with the Māori population being disproportionately affected compared to the non-Māori population. Hearing loss is an impairment that is under-recognised, under-reported and under-treated. This can be explained by the many existing barriers – the shortage of audiological services, financial cost to an individual seeking treatment, the stigma of both hearing loss and hearing aids, and healthcare seeking rates, particularly among the Māori population. This study aimed to develop a Māori language adaptive digit triplet test that could be offered remotely via the telephone and Internet as a hearing-screening test.

Three sets of recordings were made of digit triplets spoken in te reo Māori by a female speaker. Two of these sets were selected for normalisation in speech noise. Normal-hearing participants (8 listeners) with hearing thresholds ≤20 dB HL were tested to establish the intelligibility of the individual recorded digits at various signal-to-noise ratios (-13, -10.5, -8 and -5.5 dB). Psychometric functions were fitted to the intelligibility data, and the digits in each position of the triplet that had the steepest slope were selected as the final test stimuli. The level of each selected digit was then adjusted to achieve equal intelligibility as measured at the midpoints of the psychometric functions. These digits were then assembled into eight equivalent lists of similar difficulty, ready for pilot testing.

Due to low participant numbers, the pilot testing phase was not completed. Further development of this test continues as the focus of a follow-on study.

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1 Introduction

1.1 Hearing Loss

Permanent hearing loss is a substantial healthcare concern throughout the world with one in ten people affected to a mild or greater degree (Swanepoel et al., 2010a). In New Zealand the estimated prevalence is in accord with this, at 10.3% overall (Greville, 2005). Hearing loss is often under-recognised and under-treated (Dalton et al., 2003) despite its importance in all aspects of life. Spoken language forms the basis for almost all social, educational, and corporate relationships worldwide (Swanepoel et al., 2010a). Additionally, hearing loss is also under-reported by affected individuals: a study in 2003 of nearly 2700 adults aged 53 to 97 years in Wisconsin, USA found only 56% of participants with a moderate to severe hearing loss reported having a hearing handicap (Dalton et al., 2003). Participants were considered to have a hearing loss when the pure-tone average (PTA) of their hearing levels at 0.5, 1, 2 and 4 kHz was 26 dB HL or greater in at least one ear (Dalton et al., 2003). The threshold level in dB HL for what is the upper limit for normal hearing often differs among studies and clinics, ranging between 16 – 26 dB HL (Weinstein, 2009). The World Health Organisation (WHO) describes the severity of hearing impairment at any particular frequency with specific terms such as slight, moderate or severe hearing loss. The dB HL threshold levels that are used by the WHO that correspond to these terms are shown in Table 1 below. For this study, the WHO threshold levels will be used to define normal hearing as a threshold level of 25 dB HL or lower. Participants were considered as having a hearing loss if any of their thresholds at any frequency from 250 – 8000 Hz were 26 dB HL or more.

Grade of Impairment	Audiometric ISO value (average of 500, 1000, 2000, 4000 Hz)	Impairment description
0 (No impairment)	25 dB HL or less (better ear)	No or very slight hearing problems. Able to hear whispers
1 (Slight impairment)	26-40 dB HL or less (better ear)	Able to hear and repeat words spoken in a normal voice at 1 metre
2 (Moderate impairment)	41-60 dB HL or less (better ear)	Able to hear and repeat words using raised voice at 1 metre
3 (Severe impairment)	61-80 dB HL or less (better ear)	Able to hear some words when shouted into better ear
4 (Profound impairment including deafness)	81 dB HL or greater (better ear)	Unable to hear and understand even a shouted voice

Table 1: The WHO classification of hearing impairment. ISO is the abbreviation for the International Organisation for Standardisation. (Mathers, Smith, & Concha, 2000)

There are two major types of hearing loss, conductive and sensorineural. Conductive hearing loss is usually the result of middle or outer ear abnormalities affecting the mechanics of sound transmission, such as ear drum perforation, fluid in the middle ear, ossicular bone breakage, and/or excessive cerumen. Treatment for conductive hearing loss is generally surgical or medical intervention (Yueh, Shapiro, MacLean, & Shekelle, 2003). Sensorineural hearing loss is the most common cause of hearing impairment (Dillon, 2001), accounting for 90% of cases (Yueh et al., 2003). This is permanent injury to the cochlear hair cells or the auditory nerve that cannot be fixed with surgery or medicine. It is usually bilateral and gradual in nature, and occurs with noise exposure, some viral or bacterial infections, genetic disorders, and also with ageing (presbycusis). Presbycusis is characterised by a loss of high-frequency hearing (Yueh et al., 2003). Individuals with presbycusis and other causes of sensorineural hearing loss generally have difficulty separating background noise from the speech signal, whereas this is less apparent in people with conductive hearing loss (Smits & Houtgast, 2005; Yueh et al., 2003). This is due to decreased frequency and temporal resolution in the cochleae of people with a sensorineural component to their hearing loss.

In a healthy and normal ear, sound waves are conducted through the eardrum and middle ear bones as vibrations. The movement of the stapes footplate against the oval window causes pressure changes in the inner ear fluids as well as vibration of the basilar membrane. The longitudinal sound waves in the cochlear fluids result in transverse waves, also known as Bekesy's travelling waves, along the basilar membrane (Patuzzi, 2009), as shown in Figure 1A. The basilar membrane (BM) becomes less stiff from the base to the apex, and the travelling waves grow in size, and slow down the farther they travel (Patuzzi, 2009). The travelling wave reaches its maximum height at its resonant characteristic place on the BM, and promptly collapses, precluding any vibration continuing apically.

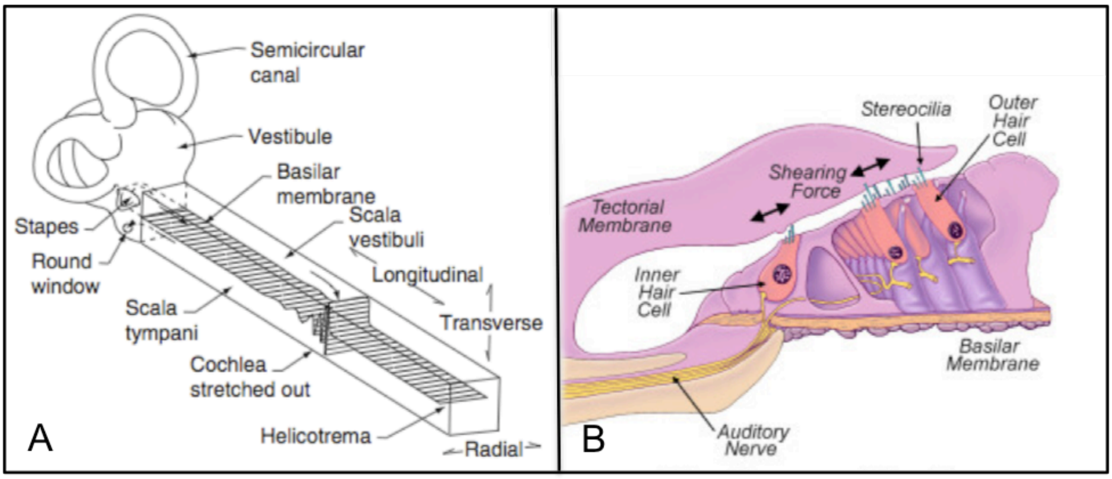

Figure 1: Panel A is a schematic of the cochlea taken from Patuzzi (2009). The cochlea is shown uncoiled to display the travelling wave. It is the transverse movement of the basilar membrane that stimulates the hair cells and neurons of the cochlea (Patuzzi, 2009). Panel B shows a diagram of the Organ of Corti, the sensory organ of the cochlea. The basilar membrane, the outer and inner hair cells and their neuronal connections can be seen. Diagram from Oghalai Lab, Stanford School of Medicine website.

The basilar membrane (BM) functions in such a manner that it can be thought of as a series of overlapping filters, or tuning curves. The changing width and stiffness of the BM along its length corresponds to site-specific regions that each respond best to a particular auditory frequency, with high characteristic frequencies at the basal end, and increasingly lower characteristic frequencies as the BM coils more apically (Patuzzi, 2009). Any site can respond to a range of frequencies, but the greatest response is generated when the stimulus frequency matches the characteristic frequency of that place (Lopez-Poveda, Barrios, & Alves-Pinto, 2007). When the basilar membrane responds to sound the active process of the outer hair cells (OHCs) amplifies the initial response and also overcomes friction in the system. This can be referred to as the "motor process", while the signal transmission role of the inner hair cells (IHCs) and the neuronal synapses can be thought of as the “sensory process” (Patuzzi, 2009).

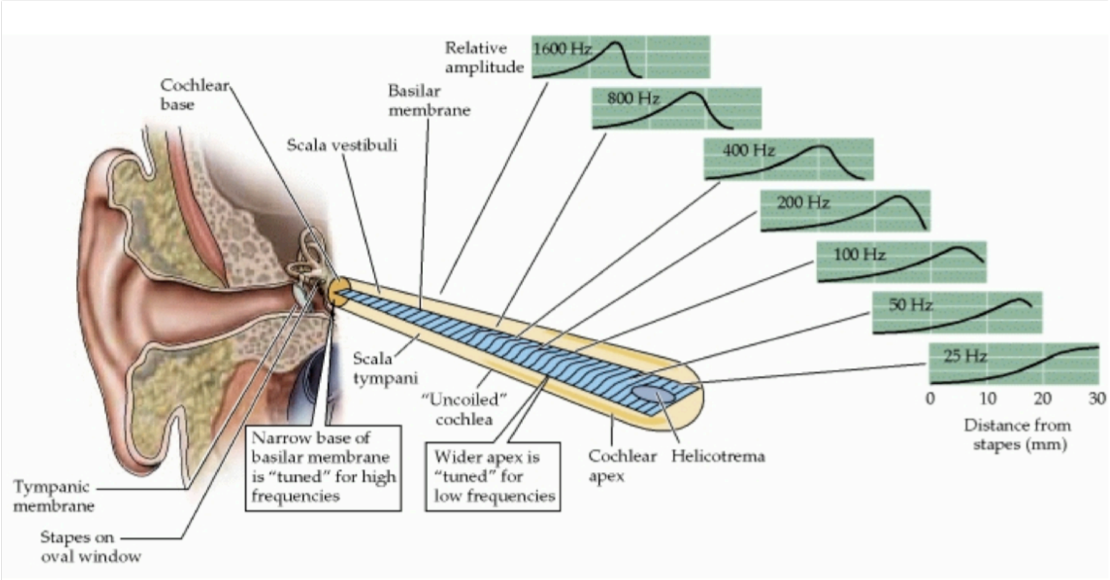

Figure 2: A diagram showing the tonotopic organisation of the basilar membrane if it were uncoiled. Image from Purves et al. (2001).

With the loss of OHCs, this motor process is adversely affected, stimulation of the basilar membrane by the sound wave isn’t amplified as it would be normally in a healthy ear. Consequently, higher intensities of sound are required for the damaged region to be stimulated to what is perceptually the same level as for a region with no damage. As higher levels of loudness are used, wider regions of the BM are stimulated by the larger vibration (Snik & Horst, 1991), and the fine tuning of the hearing system becomes more broad (Dillon, 2001). Nelson (1991) suggested that frequency resolution may only become abnormal for cochlear hearing losses greater than 40 dB HL. This might suggest other characteristic frequency regions on the BM only become adequately stimulated at the level of amplification required to elicit a response for a 40 dB HL loss, causing to broader frequency resolution as different site responses are simultaneously generated for the same stimulus. This effect in people with hearing impairments, however, is greater than can be accounted for by this explanation alone, indicating that there is other changes in frequency resolution occurring with sensorineural hearing loss (Snik & Horst, 1991). Further decrease than expected in frequency resolution may be related to death or damage of the inner hair cells or neurons at the affected regions in addition to outer hair cell damage, with research suggesting that discrimination of sounds can be strongly affected when there is a greater than 50% loss of these sensory components (Moore, 2004). As the hair cells in the cochlea deteriorate or are damaged, the ability of the hearing organ to separate out the sounds of speech versus noise is reduced.

The ability to detect a tone (even at a raised intensity level) at a BM region is not affected until the amount of loss reaches 80-90%, in which case, the targeted frequency region may be a cochlear dead region (Moore, 2004). This will result in "off-frequency" listening, where the listener responds at a certain intensity level because other regions of the BM are being stimulated, while the characteristic frequency region corresponding to the test tone has no ability to (Moore, 2004), . Thus the threshold generated for the tested frequency may not reflect the function of the cochlear region it is intended to (Halpin, 2002).

The main indicator of cochlear distortion for an individual is measuring their ability to understand speech in degraded conditions. The amount present in an individual's hearing system cannot be predicted through their audiogram thresholds or speech-in-quiet test results, it must be measured directly, such as with a speech in noise test (McArdle, Wilson, & Burks, 2005).

The impact of hearing loss extends further than having a decreased sensory ability. There has been conclusive evidence over the last decade of psychosocial wellbeing being detrimentally affected (Weinstein, 2009). In 1999 the USA National Council of Aging survey showed an association of hearing loss with sadness, depression, anxiety, paranoia, and lessened social activity in the elderly population (Weinstein, 2009). There is further evidence for hearing loss impacting negatively on employment status and pursuit of quality interpersonal communication (Swanepoel et al., 2010a).

Hearing aids are often suggested as a tool to help alleviate the disability caused by a loss of hearing sensitivity. These devices can amplify sound to an audible level, and with increasingly sophisticated signal processing strategies, they can to an extent selectively increase speech sounds while suppressing what is identified as noise (Dillon, 2001).

Assistive Listening Devices (ALDs) are equipment that help detection of speech and sounds but are not worn completely on the head or body, and can be an alternative to, or used as well as, hearing aids. These commonly comprise of a sensor (e.g. a doorbell) connected to an output signal such as a flashing light or vibrator that a person with hearing impairment can easily detect (Dillon, 2001). An ALD can also be a device that is used to amplify a specific auditory source, for example, one may be used for listening to the TV, with a personal wireless headphone set that directly receives a signal from a device connected to the TV sound output. Other ALDs may be an amplified telephone, an alarm that is also connected to a bed-vibrating device, or an FM system – an instrument that uses a radio FM frequency to transmit a speech signal from a microphone to a receiver system worn on an individual's ear (Dillon, 2001).

Despite the technology being available to address hearing loss, it is an impairment that is often lived with, rather than attended to. A report in 2005 concerning hearing impaired and deaf people in New Zealand collated results from several previous surveys, and found 34,500 individuals indicated that they felt they had a hearing loss that would warrant hearing aids, but did not have them (Greville, 2005).

1.2 Barriers to addressing hearing loss

There are different kinds of barriers to seeking advice and help for hearing loss. Concerns regarding access to healthcare are commonly cost-related in New Zealand (Schoen et al., 2002), and geographical isolation creates a financial barrier additional to clinical fees to reach services that are only provided in more populated areas. This is a practical issue for many in New Zealand, where the land area is large (268, 021 km^2) and the population is relatively small (4.37 million) (Bascand, 2010). People and communities are spread out, with many in rural areas where specialised healthcare is not viable. With up to 10.3% of people in these communities potentially having some degree of hearing loss (Greville, 2001), there is a need to address the limitation of hearing services' physical locations.

Another issue is that many people do not consider seeking professional opinions on their hearing status, despite it being well-known that hearing loss becomes more common with ageing (Smits, Kapteyn, & Houtgast, 2004), almost 50% of those over 75 years have some hearing loss (Wallhagen, 2010). Many individuals may be simply unaware of their hearing impairment due to the gradual onset of presbycusis (Yueh et al., 2003). It can also go undiagnosed because individuals often only have subjective measurements of their hearing (Smits et al., 2004), and because older adults tend to compare their own hearing status against that of their peers, their idea of “normal” becomes skewed (Nondahl et al., 1998). Individuals tend to adapt their social activities to the gradual deterioration of their hearing, without necessarily identifying a hearing loss as the reason. Withdrawing from demanding social situations and avoiding demanding auditory environments is often attributed to a consequence of ageing and “getting old” rather than due to hearing difficulties. This adaptation tendency can prolong a person’s unawareness of their own hearing loss, as they are no longer in as many situations where they would have problems (Koopman, Davey, Thomas, Wittkop, & Verschuure, 2008). Identifying hearing loss then becomes a matter of whether an individual decides to approach a professional due to his or her own concerns. Thus it is not perhaps unsurprising that there is a high prevalence of undiagnosed hearing loss in the population (Jansen, Luts, Wagener, Frachet, & Wouters, 2010).

A further important factor in seeking treatment for hearing loss is the perceived stigma of hearing loss and hearing aids. Individuals often do not want to acknowledge that they have a hearing loss for fear that this will indicate to others that they are becoming old, or are physically and/or mentally inferior (Wallhagen, 2010). A qualitative longitudinal study of adults older than 60 years with hearing loss by Wallhagen (2010) found the perception of a stigma for wearing hearing aids and having a hearing impairment contributed to resistance to hearing testing, seeking of treatment for hearing loss and also the wearing of hearing aids. Furthermore, studies have found that older adults simply accept hearing loss as a normal part of ageing, and do not think of hearing loss in terms of being a health problem that should receive attention in the same way that they would perceive blurred vision as needing correction by use of spectacles (Nondahl et al., 1998) .

1.3 Hearing Screening

Hearing screening is a useful tool to help identify people who could benefit from audiological intervention (Yueh et al., 2003). Its underlying purpose is to allow investigation of hearing loss, and subsequent professional care. This can be especially important when hearing loss is a symptom of a medically significant pathology (Schow, 1991).

Hearing screening uses efficient, simple tests that divide people into two groups – pass and fail – according to the criteria specific to that test (ASHA, 1997-2010). There are several types of hearing screening tests available. Conventional audiometric screening uses an audiometer and is performed in clinical settings. The individual presents at the clinic, and is seen by an audiometrist or audiologist. Audiometric hearing screening method will usually test air conduction thresholds only, and tests hearing acuity down to a previously determined level that is within the normal range e.g. 10 dB HL, below which threshold seeking does not occur. Screening usually only tests the speech frequencies as well, with no inter-octaves included: 0.5, 1, 2, 4, 8 kHz. This allows the tester to establish whether or not the client has normal air conduction thresholds while avoiding spending time attaining thresholds that give no more functional information. If the screening identifies a loss at some or all frequencies, then a follow-up diagnostic audiogram will be recommended, where both air and bone conducted sound will be used, as well as speech and immitance testing. For an audiology clinic, hearing assessments incur the cost of the audiologist's time, as well as that of the frontline staff that administrate the appointment. Further costs are the equipment and space used, and disposable materials required in testing (Hosford-Dunn, Roeser, & Valente, 2000). The advantages of this method are that the people presenting for hearing screening are already somewhat motivated or interested in their hearing status, have the results and recommendations relayed to them directly after by a professional, and can be booked for a follow-up appointment immediately if desired. The disadvantages of conventional clinical audiometry screening are that individuals must travel to the clinic, and, dependent on the clinic, pay for the screening appointment – both of which can be deterrents until a person feels their hearing is bad enough to warrant the time and cost.

Hearing assessment questionnaires and immitance testing are screening options as well (Schow, 1991). Hearing assessment questionnaires are essentially self-tests, and include the Five-minute Hearing Test, the Hearing Handicap Inventory for the Elderly - Screening version (HHIE-S) and the Self-Assessment of Communication (Smits, 2005). However, these tests measure a person's perceived disability as caused by their hearing loss, so may be limited in helping a person to realise their impairment needs (Smits, 2005). There are also remote screening options (Swanepoel & Hall, 2010b), such as web-mediated audiometry, where a pure tone audiogram is obtained using a network between the assessor's and the client's computer (see Figure 3). Results from this method did not deviate significantly (no more than 1.79 dB) from the thresholds obtained with conventional audiometry performed with an audiometer (Seren, 2009). Telephone-based pure tone screening methods are also available, however in some countries they lack supporting research (Smits & Houtgast, 2005). A survey of 62 countries and their audiological organisations demonstrated a need for more audiologists, as indicated by 86% of respondents (Goulios & Patuzzi, 2008). This widespread shortage of audiological services (Goulios & Patuzzi, 2008; Swanepoel & Hall, 2010b), suggests a need for accessible options in areas where healthcare is not easily available.

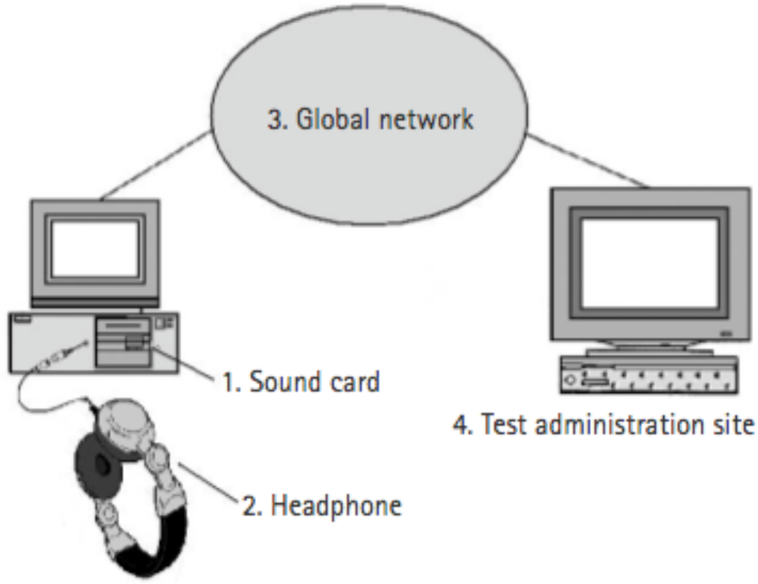

Figure 3: Diagram of the Web-based hearing screening system, as used by Seren (2009).

Hearing screening tests can help increase awareness of potentially existing hearing difficulties for a person who is suspicious of a problem, but reluctant to make a commitment, of either time or cost, to a professional exam. Certain questionnaires (e.g. the HHIE-S) could be made available for public use to determine hearing difficulty, but these can be limited as they are essentially a self-test, and as such, will only reflect whether an individual believes their hearing causes any issues (Smits et al., 2004). An objective measure of hearing function that can be performed in a familiar situation, such as a person's home, may be a useful first step for these individuals who are interested in their hearing status, but not sure a formal assessment is required (Smits et al., 2004). If a person is indicated to have a hearing loss through such a screening test, they may be more confident that obtaining a professional opinion will be justified, or at the very least be aware that arising communication difficulties may be due to their hearing.

Wallhagen (2010) suggests that having routine hearing screening built into healthcare systems could be a way to normalise the idea of hearing loss, and emphasise hearing ability as a part of overall health and wellbeing. Wide implementation of this could help change the societal perspective that finding hearing loss is a step on the path to decrepitude, to a more positive approach of monitoring hearing as a part of maintaining general wellbeing (Wallhagen, 2010). A nationally available hearing screening test that is available for adults of all ages for use in the home environment could similarly help people's acceptance of hearing loss as something that affects many people, across a range of ages, without adding pressure to the public health system. A remotely available hearing-screening test could become an additional tool for general practitioners to suggest for patients' use at routine check-ups, particularly in the elderly population. For patients who are naïve to their hearing status, the GP could suggest patients use the self-test, and to continue self-monitoring every few years – returning for an appointment if they become concerned.

An automatic, objective self-test that can be performed over the phone (Smits et al., 2004), such as the digit triplet test (DTT) could answer such a need.

1.4 The Digit Triplet Test

While speech-in-quiet tests are often employed as a part of standard audiological test batteries, research shows that they are not good predictors of an individual's performance in speech-in-noise tests (McArdle & Wilson, 2009). Furthermore, pure-tone audiometry has been shown to be an imprecise predictor of how an individual hears in background noise. Considering difficulty understanding speech in the presence of background noise is commonly considered to be the greatest problem that people with hearing loss experience (Kramer, Kapteyn, & Festen, 1998), a screening method that directly tests this ability would be useful (Smits et al., 2004). In the presence of background noise, the speech reception threshold, or $SRT_{n,}$ is a term used to convey the signal-to-noise ratio (SNR) at which an individual can correctly recognise 50% of the speech material. The digit triplet test (DTT) was first developed for use as a SRT_n test that could be performed over the phone (Smits et al., 2004). It should be noted that speech-in-noise tests such as the DTT are not sensitive for detection of hearing loss of a purely conductive nature, as it is the deterioration that occurs with sensorineural hearing loss that leads to problems understanding speech in noise (Smits & Houtgast, 2005). However, as sensorineural hearing loss accounts for 90% of cases (Yueh et al., 2003), the majority of people using this test who are experiencing hearing loss should still be identified accurately.

The DTT is an adaptive speech in noise test, where the signal to noise ratio (SNR) changes throughout the test by using the accuracy of the response given for the last presentation as a determinant for the SNR in the next presentation. Adaptive listening tests are simple, highly efficient and reliable even when used with a small sample size (Levitt, 1970). When an individual identifies the digits correctly in a response, the loudness level of the digit triplet will decrease in the subsequent presentation while the background noise remains at a fixed level, decreasing the SNR. When a mistake is made, the loudness level of the digit triplet will begin to increase in level, increasing the SNR, until the individual's response improves. A response is only correct when all three digits of the triplet are entered correctly (Smits et al., 2004).

The use of digit triplets (e.g. 6-8-2, 5-4-1) instead of single or double digits increases the accuracy of the test without becoming demanding on an individual's working memory (Smits et al., 2004). Digit triplets also generate steep psychometric functions, making them an accurate stimulus for estimating speech reception thresholds with a relatively low standard deviation (Ozimek, Kutzner, Sek, & Wicher, 2009). Digits are useful as the speech material, as they are common and familiar words in spoken language, but relatively meaningless when presented without context, allowing a list of digit triplets to be presented several times without the learning effect influencing the resulting SRT_n (Ozimek et al., 2009; Smits et al., 2004). Using digits also means that a keypad can be used for the test, allowing the DTT to be used on a telephone, extending its use to wide-reaching screening applications (Ozimek et al., 2009).

The Dutch DTT was implemented on a national scale in 2003 (Smits et al., 2004). This test was initially performed over the telephone, and later also over the internet. This DTT provided three possible results for participants' hearing status at the end – "good" (SNR <2.9), "insufficient" and "poor" (SNR > 5.6). In a follow-up study (Smits, Merkus, & Houtgast, 2006) for the Dutch DTT (Smits et al., 2004) 881 participants were followed up by a mailed questionnaire as to whether they had followed the recommendation to see a medical or audiological professional if prompted to do so at the end of the test. Over half (57%) of those who had used the test by telephone and achieved a "poor" hearing status result sought consultation with someone in the medical or audiological field if they had not already done so in the past, as did 46% of those who achieved an "insufficient" hearing status result. These figures may not be truly representative of the effectiveness of the test, however, as only those who had indicated they were amenable to further contact and also returned the questionnaire were included (Smits et al., 2006).

While speech-shaped white noise has been used in some DTT versions, using speech noise created by superimposing speech material has been found to produce steeper intelligibility functions (Ozimek et al., 2009). Noise created by superimposing digit repetitions from the same recordings used for the speech material results in a noise spectrum that is virtually identical to the long-term spectrum of the digit speech material used (Jansen et al., 2010; Smits et al., 2004). Using speech noise material generated from the speech material recordings means that any filtering that occurs to the recorded speech when transmitted via the phone or internet will also equally affect the noise. This allows the test to be used on many different models of telephones and with different headphone types as the SNR of the presentations is unaffected.

Gustafsson & Arlinger (1994) cite several studies that used a speech-noise masker made of the speech from a single speaker that is also either amplitude modulated periodically, or modulated by the speech of a single talker. Both modulation types were shown to give higher speech intelligibility scores than unmodulated speech noise. The authors deduced that this reflected more speech information being detected during the intervals of lower speech noise, an advantage that was not counter-balanced by the intervals of increased levels of speech noise (Gustafsson & Arlinger, 1994). Their own study using several listener groups (young and normal hearing, elderly and normal hearing, and elderly and hearing impaired) showed similar results – speech recognition is generally better when the masking noise is amplitude modulated (Gustafsson & Arlinger, 1994). However, hearing impaired people get less benefit for speech recognition in amplitude modulated background noise than normal hearing individuals, and this is likely due to reduced temporal and possibly spectral resolution abilities, affecting their ability to make use of the intervals of lower speech noise (George, Festen, & Houtgast, 2006). This means that people with hearing impairments are not as good as recognising speech in modulated noise, as they are in steady state noise when compared to normal hearing listeners in the same conditions. As the normal hearing listener is not adversely affected by the modulating background noise, and in fact gains benefit from it, but the hearing impaired listener is, modulating the background noise used for a speech in noise test increases the efficiency of the test – the difference in ability between the two groups is greater with this alteration included (Hagerman, 2002).

Similarly, Peters, Moore & Baer (1998) found using speech noise with temporal dips resulted in elderly listeners who had a moderate to severe cochlear hearing loss requiring a SNR about 19 dB higher than young, normal hearing individuals. Temporal dips are found in speech, such as in pauses, unvoiced consonants (p, k) and other low-energy speech sounds e.g. n, m (Peters et al., 1998), as such, people with normal hearing can achieve a similar level of performance at a lower SNR when listening for a target speech signal in the presence of a background competing single talker compared to when speech-shaped noise is used (Moore, 1995, p. 167). During a temporal dip, the SNR increases, and people with normal hearing can take advantage of this to add more information to the speech signal while people with hearing impairments cannot. This type of “glimpsing” of the target speech material requires a wide dynamic range, as useful information may be in any given frequency band during the temporal dip (Moore, 1995).

1.5 The DTT in the Māori language

The DTT has been developed in several languages since its initial production in Dutch (Smits et al., 2004). Versions exist in French (Jansen et al., 2010), Polish (Ozimek et al., 2009), and German (Warzybok, Wagener, & Brand, 2007). New Zealand has two official spoken languages, English, and the indigenous te reo Māori. A DTT in New Zealand English was developed in 2011 by King et al. (S. King, 2011). While there is some evidence that little difference in scores occurs between native and non-native speakers of English for digit SRT (Ramkissoon, Proctor, Lansing, & Bilger, 2002), Warzybok, et al. (2007) found that this was true only when the DTT was presented via headphones, with non-native speakers having poorer speech perception when the digits-in-noise test was performed over the telephone.

When developing a hearing-screening test that is aimed for national use it is important that it is truly accessible to the population most at risk. The 1991/1992 New Zealand Census study established that Māori had a higher prevalence of hearing loss compared to non-Māori (12.1% vs. 9.6%) when adjusted for life expectancy differences between the two populations (Greville, 2005). Data from the 2001/2002 Census disability survey showed that hearing loss was the most common disability for Māori between 15-24 years of age, with a prevalence of 3.6% compared to 1.0% for non-Māori in the same age band (Greville, 2005). This ethnic difference disappears in the over-65 age band due to differing life expectancies between the two populations (Greville, 2005). Māori are also over-represented in most socio-economically disadvantaged groups of New Zealand society (Baxter, 2002). Concordantly, the Commonwealth Fund 2001 International Health Policy Survey identified that Māori people were more likely than European New Zealanders to go without medical care when needed due to cost (Baxter, 2002), with a 2006 study determining that Māori are twice (34% vs. 18%) as likely to have gone without healthcare in the last year due to cost compared to other ethnic groups (Ellison-Loschmann & Pearce, 2006). This identifies an important factor in the Māori population's sub-optimal access to healthcare (Baxter, 2002). Furthermore, there is evidence that indigenous populations have an increased occurrence of hearing loss and middle ear disorders (Goulios & Patuzzi, 2008; Pang-Ching, Robb, Heath, & Takumi, 1995).

The New Zealand Health Strategy (2000) cites one of the most effective means of reducing health disparities is to use prevention strategies and "improve delivery of treatment services through mainstream enhancement and provider development" (A. King, 2000). An important part of "provider development" would be to have services available in a bilingual manner, allowing them to be received in the language that an individual is most comfortable with. Considering the current socio-economical and healthcare seeking rates of the Māori people in New Zealand, a hearing-screening test that is available in the Māori language and in a remote capacity may help alleviate issues associated with Māori seeking hearing-related healthcare.

The goal of this project is to develop a normalised Māori language version of the Digit Triplet Test as part of the New Zealand Hearing Screening Test.

2 Methods

2.1 Recording and Processing of Speech Material

The speech material used was the numbers from 0 – 9 spoken in te reo Māori. To avoid correct guesses in the normalisation and testing phases by deduction, the only monosyllabic number within this number range, "wha" ("four" in English) was not included. All other numbers used were disyllabic.

A female speaker fluent in Māori was asked to read a number of lists of triplets and a carrier phrase "ko nga nama…" ("the numbers…") using natural intonation and pauses. The digits within each triplet were spoken as single digits e.g. seven-six-two, not seven hundred and sixty two. To enable the best takes to be selected, the speaker was given three lists to repeat, each containing nine different triplets. Each digit was spoken in each of the three digit positions once per list, giving three versions of the same digit at each position in the triplet. The carrier phrase was repeated before 10 of the triplets.

The digits and carrier phrase were recorded as digital files at a sampling rate of 48 kHz using a SE Electronics SE 2200A microphone (serial number SO58345). The program Cubase LE version 1.0.8, build 104, was used to record the speech material, via an Alesis i02 USB Soundcard (with an incorporated pre-amp). Recordings were made in a sound-treated room in the Ōtākaro building of the University of Canterbury.

The digital recordings were then split into separate sound files – one file for each of the three versions of each digit at each position in the triplet, as well as a file for each of the ten versions of the carrier phrase. The best two takes of each digit at each position and a single version of the carrier phrase were selected qualitatively by the author and her two supervisors. 100 ms of ambient room noise was retained on either side of the spoken material, with an ~100 ms linear fade in and out at the front and back ends respectively. This processing was performed using Sony Sound Forge (version 9.0, build 245) software.

2.2 Generation of speech noise

To generate speech noise, each of the individual digit recordings were randomly superimposed 10,000 times within a 10 s looped sound file using an automated process. As shown in Figure 4, this process results in noise with a spectrum that is nearly identical to the speech signal. By using noise with the same spectral components as the speech material, the SNR of the stimuli would not be affected when listened to through a band-limited transducer such as a telephone or broadband signal, as the frequency components for each will be equally filtered. Additionally, changes to the level of the presentation of the test (i.e. by speaker or phone receiver volume) do not alter the ability of the test to determine whether a listener has a hearing loss or not, if the adjustments are within reasonable limits (Smits et al., 2004).

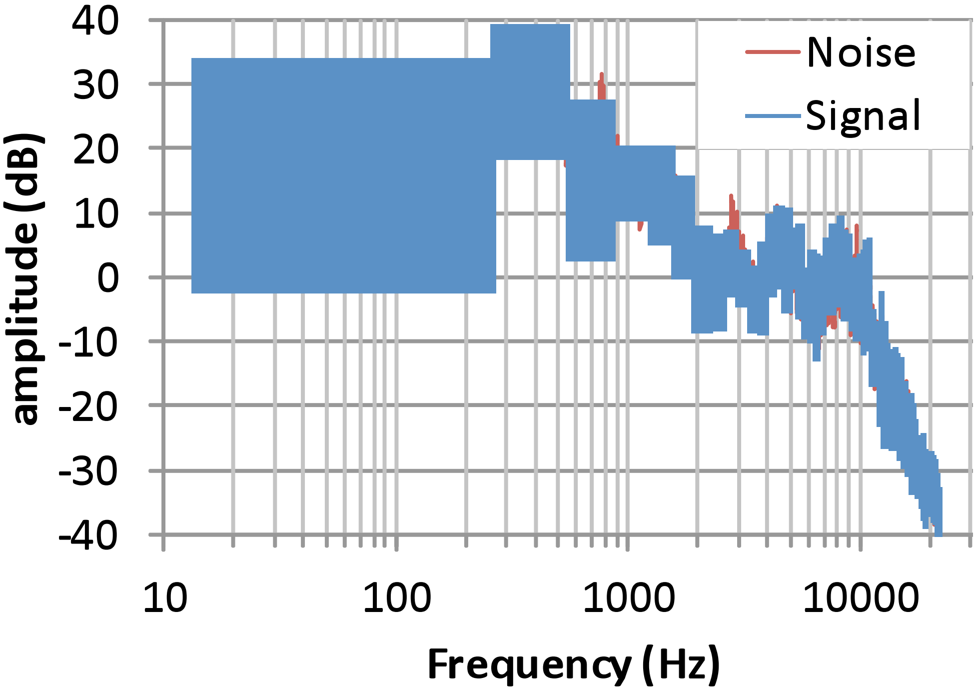

Figure 4: Power spectra of the digit test material ("signal") and the speech noise.

2.3 Test Material Setup

The digit recordings were compiled into digit triplets with the carrier phrase preceding them. The triplet lists were created using software especially designed for this purpose by Dr. Greg O'Beirne.

Triplet combinations where two or more consecutive digits were the same in a triplet (2-5-5, 3-3-3, or 8-8-1 for example) were excluded as possibilities, as were those that included the number 4. This resulted in 576 candidate triplets (from an original 1000 possibilities). 144 of these candidates were selected and sorted into four lists of 36 triplets, such that every digit appeared four times in each position within each of these lists. Each of the four lists was to be presented at a different SNR to establish the psychometric functions of each digit, as described below. Of the four appearances of each digit at each position at each SNR, two used the recording from Take 1 and two used the recording from Take 2. All in all, there were 144 unique triplets presented to each listener, with each digit position containing two repeats of two takes of each of nine digits at four SNRs.

In the final version of the test, the triplets need to be of equal difficulty so as to optimise the reliability of the test (Ozimek et al., 2009; Smits & Houtgast, 2007). To achieve this, two normalisation phases were undertaken.

2.4 Method Outline

The first phase, digit normalisation, produced psychometric functions for the intelligibility of each digit when listened to across four different SNRs. The four SNRs used in this stage were -13, -10.5, -8 and -5.5 dB. These four SNRs were distributed around an estimated midpoint SNR of 11.3 dB SNR, which was determined from the results of a small number of subjects with normal hearing performing the preliminary test. Three of the four SNRs used were above this 50% level, as higher target levels have been shown to produce more accurate estimates of the psychometric function than those centred closer to the 50% level (Green, 1990). All testing was conducted in the sound-treated booths of the Audiology Clinics in the Communication Disorders Department at the University of Canterbury.

Noise was presented at a fixed 65 dB SPL throughout the tests, similar to the level used in other DTTs, as shown in Table 2 below. Each triplet was preceded by the carrier phrase “Ko nga nama…” (“the digits…”). Each speech segment lasted for approximately 3.7 s. The noise commenced 500 ms before the speech and finished 200 ms after it, giving a total length for each sample of 4.4 s. The onset and offset of the noise stimulus was linearly ramped for a length of 50 ms.

Language (Author, Year)	Noise level (dB SPL)
Dutch (Smits et al., 2004)	73 dBA
Polish (Ozimek et al., 2009)	70
French (Jansen et al., 2010)	65
German (Wagener, Eeenboom, Brand, & Kollmeier, 2005)	65

Table 2: Languages and fixed noise level used in other DTTs

2.5 Participant Selection

Participants were adult volunteers (18 years or older) who had responded to advertisements for the study. Volunteers were assessed for their suitability in two ways. First they had to identify their level of fluency for spoken Māori language. Volunteers were asked to select a category on a table (Figure 5) included on the information sheet that most closely reflected their language ability. While knowledge of Māori numbers is widespread in New Zealand, even amongst those who do not speak the language, participants would be listening in challenging conditions, and language ability needed to be such that it wouldn't cause added difficulty. Initially, only the volunteers who chose a fluency level of "fairly well" or higher were eligible for the study, however, continual difficulties with recruiting adequate participant numbers from the onset of advertising meant that this condition was relaxed, with two participants who indicated they could speak Māori "not very well" also being included.[1]

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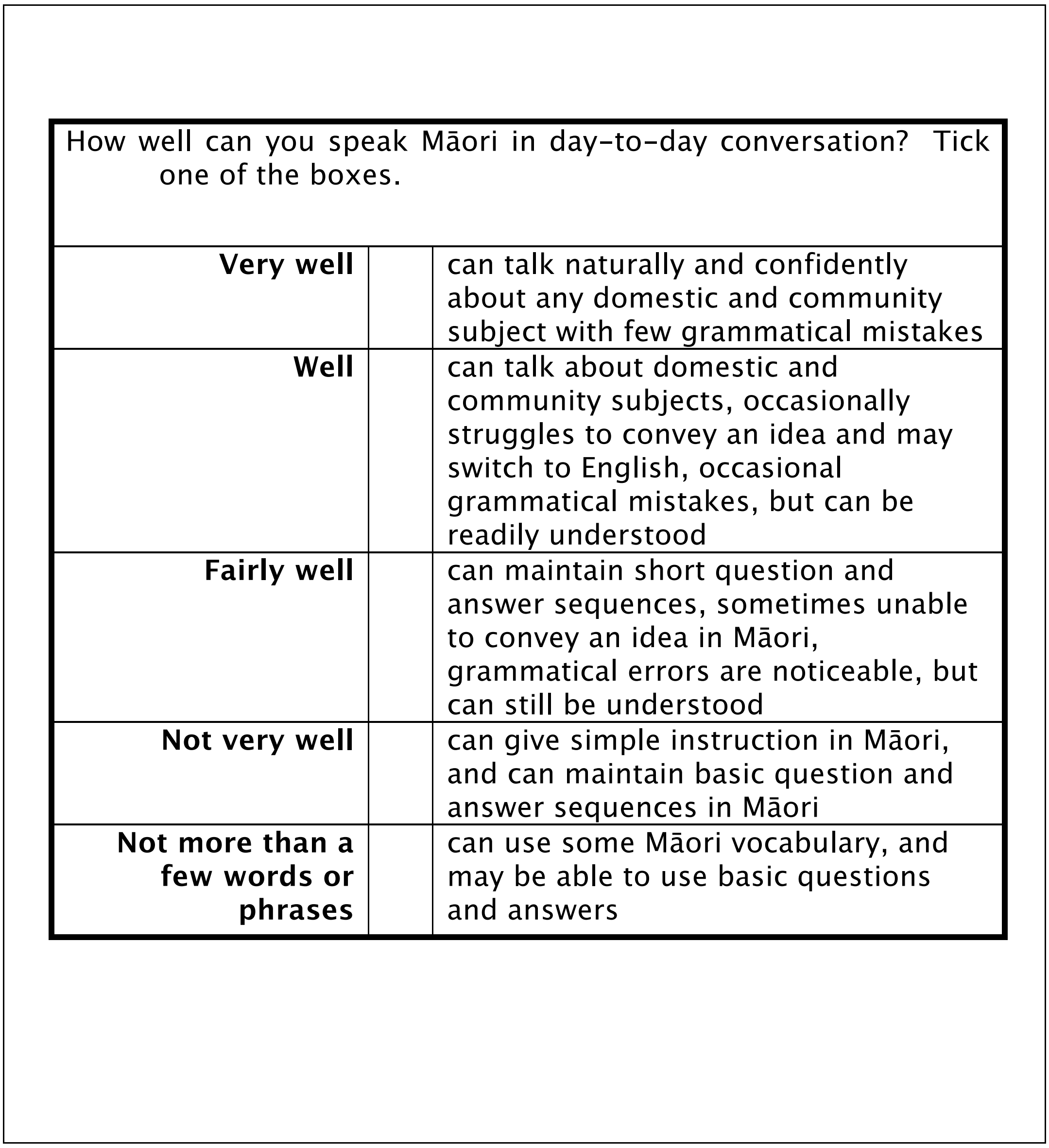
[1] One of these participants did not perform reliably and was subsequently excluded from the analysis.



How well can you speak Māori in day-to-day conversation? Tick one of the boxes.

Very well	☐	can talk naturally and confidently about any domestic and community subject with few grammatical mistakes
Well	☐	can talk about domestic and community subjects, occasionally struggles to convey an idea and may switch to English, occasional grammatical mistakes, but can be readily understood
Fairly well	☐	can maintain short question and answer sequences, sometimes unable to convey an idea in Māori, grammatical errors are noticeable, but can still be understood
Not very well	☐	can give simple instruction in Māori, and can maintain basic question and answer sequences in Māori
Not more than a few words or phrases	☐	can use some Māori vocabulary, and may be able to use basic questions and answers

Figure 5: The question and table included in the information sheet for participants to indicate their ability to understand Māori in a spoken language context

Volunteers who had an acceptable level of language fluency then had their hearing tested to ascertain that they were suitable for the part of the study they were volunteering for, either having normal hearing or a hearing loss (see Chapter 2.6.1 for the hearing screening procedure).

2.6 Digit Normalisation

After giving informed consent, participants underwent a hearing screening to establish their hearing as within normal limits. Normal hearing in each ear was defined as audiometric thresholds at 25dB HL or less across the frequencies 250 – 8000Hz (Dalton et al., 2003), which is the dB HL threshold level that denotes hearing loss as defined by the World Health Organisation (Table 1). Initially there were 10 participants (2 male, 8 female) tested for this phase, with a mean age of 26.7 years and an age range of 19 – 52. Unfortunately a software error caused the results of these participants to be unusable for the normalisation data, though the information did help to establish the SNR range for further testing.

Following a participant recall, 5 participants returned to re-sit the test, and 3 new participants were recruited. This resulted in a total of 8 (3 male, 5 female) participants with normal hearing, with a mean age of 22.75 years and an age range of 19 – 32. Table 3 below shows the age and sex distribution for these individuals.

	Age (years)			
Sex	(18-24.99)	(25-29.99)	(30+)	Total
Female	4		1	5
Male	2	1		3
Total	6	1	1	8

Table 3: The age and sex distribution of the participants for the digit normalisation phase

2.6.1 Procedure for hearing screening

Participants were seated inside a soundproof booth in the Audiology clinics in the Department of Communication Disorders. They were asked for their age, and their own view of their hearing. Using an otoscope, the insides of participants' ears were inspected for general health, presence of any wax and eardrum status.

Participants were instructed to press a response button whenever they heard a tone in either ear, regardless of how soft it sounded. They were then fitted with Telephonics TDH-50P headphones (serial number SN C7088) through which they would hear the tones.

The test commenced, using a Grason-Stadler GSI 61 audiometer. Air conduction thresholds were screened to 10 dBHL across the frequencies 250, 500, 1000, 2000, 4000 and 8000 Hz, using the modified Hughson-Westlake method for audiological testing (Carhart & Jerger, 1959). Both ears were tested across all frequencies.

Participants were verbally informed of the results – either normal hearing levels, or an elevation of thresholds. Where hearing loss was found, participants were asked to participate instead in a later stage of the research.

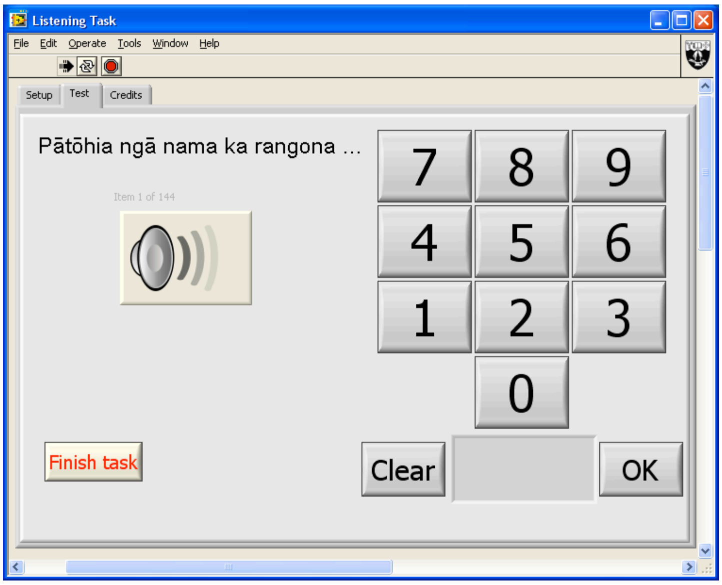
2.6.2 Procedure for listening to digits in noise

Participants with established normal hearing were asked to listen to the lists of digit triplets for the digit normalisation phase, which were presented binaurally using Sennheiser HD 215 headphones. The test was run on a computer using the Windows XP (2002) operating system. The participants were not informed of any omitted digits, and 0 – 9 inclusive were available options for their responses.

They were instructed as follows:

1. They would hear the triplets spoken by a woman at varying levels in the presence of a fixed-level (65 dB SPL) background noise. They were to ignore the noise and enter the digits they heard using a keypad or touch-screen interface (see Figure 6) on the computer running the test. They were informed that digits might repeat within a triplet, and each triplet would be preceded by the carrier phrase "Ko nga nama…"

2. Participants could correct their answer before continuing by using the "backspace" key if required. They were instructed to enter what they thought the digit might have been in any instances that they were not certain. They needed to press "Enter" to lock in their answer, after which the next presentation would immediately commence.



Pātōhia ngā nama ka rangona ...

Item 1 of 144

Figure 6: The interface used for the normalisation phases

Listening to the digit test took 15-25 minutes for participants to complete.

The participants' responses were saved to a data file at the end of each test. There were two takes of each digit from 0 – 9 (excluding 4), at each position in the triplet, and all were presented at four different SNRs. Each digit was scored as correct or incorrect on an individual basis, not as a whole triplet. This allowed intelligibility functions for each digit at each position to be generated, using the Solver function (Fylstra, Lasdon, Watson, & Waren, 1998) of Microsoft Excel.

After eleven participants had been tested, it was noted that the SNR of the midpoint of a few of the digit recordings fell outside the test range (either above it or below it), resulting in flat psychometric functions that would not enable those recordings to be normalised. Rather than continue to collect this data, an intermediate adjustment was undertaken at this point. Recordings that were identified correctly at all SNRs were made more difficult, and those that were too difficult were adjusted so that they were presented at a higher SNR. After this intermediate adjustment step, the adjusted recordings were put back into the test for further participants to listen to.

The final digit normalisation step analysed the results from this data set to determine the best take of each digit at each position in the triplet by generating intelligibility slopes and midpoints for each as described above.

For each digit-position recording combination, the version with the steepest intelligibility function and lowest mean squared error (i.e. the closest match between the data points and the fitted intelligibility function) was chosen as the best take to be used in further testing.

2.6.3 Digit Normalisation Results

Psychometric data was obtained from participants NHM 4, 7, 8, 10, 11, 12, 13, and 14. As there were a small number of participants used in this stage, it was possible for lapses and guesses to have a significant impact on the mean results. For example, a participant may have had a lapse of concentration during a high SNR trial and got it wrong, or may have guessed at the answer for a low SNR trial and got it right.

To reduce the influence of lapses and guesses, a trimmed mean of the percentage correct scores was obtained for each combination of digit, take, and SNR by discarding both the best and worst score from the calculation. The resulting mean was therefore calculated from six data points, rather than eight, but gave better fits for the psychometric functions (i.e. a lower mean squared error). For each digit/position/recording combination, the version with the steepest intelligibility function and best fit to the intelligibility function (a sigmoidal shape and low mean squared error) was chosen as the best take to be used in further testing (Table 4). The psychometric functions for the version of each digit chosen for position 1, 2 and 3 in the triplet are shown in Figure 7, Figure 8 and Figure 9 below, respectively.

Take 1				Take 2				Notes
Position 1	**Slope at midpoint:**	**mserror**	**Take used?**	**Position 1**	**Slope at midpoint:**	**mserror**	**Take used?**	
0	**19.23 %/dB**	**0.0004**	**Yes**	*0*	*11.29 %/dB*	*0.0008*	*No*	
1	*16.39 %/dB*	*0.0055*	*No*	**1**	**19.23 %/dB**	**0.0004**	**Yes**	
2	*4.91 %/dB*	*0.0077*	*No*	**2**	**7.39 %/dB**	**0.0016**	**Yes**	
3	**14.51 %/dB**	**0.0015**	**Yes**	*3*	*15.60 %/dB*	*0.0083*	*No*	Take 2 lowest SNR value scores 0%
5	**7.24 %/dB**	**0.0025**	**Yes**	*5*	*0.00 %/dB*	*0.0159*	*No*	
6	**13.36 %/dB**	**0.0056**	**Yes**	*6*	*161.43 %/dB*	*0.0002*	*No*	Take 2 slope too high
7	**7.50 %/dB**	**0.0001**	**Yes**	*7*	*11.13 %/dB*	*0.0009*	*No*	Take 2 non-monotonic
8	**35.15 %/dB**	**0.0017**	**Yes**	*8*	*16.31 %/dB*	*0.0003*	*No*	
9	**16.94 %/dB**	**0.0003**	**Yes**	*9*	*13.67 %/dB*	*0.0005*	*No*	
Position 2				**Position 2**				
0	*10.88 %/dB*	*0.0110*	*No*	**0**	**16.69 %/dB**	**0.0067**	**Yes**	
1	**13.75 %/dB**	**0.0001**	**Yes**	*1*	*14.35 %/dB*	*0.0069*	*No*	Take 2 non-monotonic
2	**8.01 %/dB**	**0.0011**	**Yes**	*2*	*3.35 %/dB*	*0.0055*	*No*	
3	**32.71 %/dB**	**0.0000**	**Yes**	*3*	*9.31 %/dB*	*0.0006*	*No*	
5	**22.57 %/dB**	**0.0000**	**Yes**	*5*	*7.09 %/dB*	*0.0058*	*No*	
6	**29.97 %/dB**	**0.0000**	**Yes**	*6*	*17.62 %/dB*	*0.0005*	*No*	
7	**27.35 %/dB**	**0.0010**	**Yes**	*7*	*11.19 %/dB*	*0.0067*	*No*	
8	**21.59 %/dB**	**0.0008**	**Yes**	*8*	*9.41 %/dB*	*0.0106*	*No*	
9	*5.86 %/dB*	*0.0005*	*No*	**9**	**11.19 %/dB**	**0.0021**	**Yes**	
Position 3				**Position 3**				
0	**16.64 %/dB**	**0.0048**	**Yes**	*0*	*118.57 %/dB*	*0.0000*	*No*	Take 2 slope too high
1	**15.27 %/dB**	**0.0021**	**Yes**	*1*	*11.32 %/dB*	*0.0309*	*No*	
2	*34.65 %/dB*	*0.0066*	*No*	**2**	**17.15 %/dB**	**0.0014**	**Yes**	Take 1 slope too high
3	**33.91 %/dB**	**0.0068**	**Yes**	*3*	*22.21 %/dB*	*0.0064*	*No*	
5	**9.85 %/dB**	**0.0139**	**Yes**	*5*	*5.91 %/dB*	*0.0025*	*No*	
6	*11.06 %/dB*	*0.0003*	*No*	**6**	**16.20 %/dB**	**0.0012**	**Yes**	
7	**28.14 %/dB**	**0.0000**	**Yes**	*7*	*220.16 %/dB*	*0.0025*	*No*	Take 2 slope too high
8	*80.86 %/dB*	*0.0035*	*No*	**8**	**9.80 %/dB**	**0.0019**	**Yes**	Take 1 slope too high
9	**24.68 %/dB**	**0.0002**	**Yes**	*9*	*132.28 %/dB*	*0.0002*	*No*	Take 2 slope too high

Table 4: The midpoint slopes and mean squared error values for take 1 and Take 2 of each digit in each position. From this data, the best version was selected. The "Notes" column provides further insight into the reasoning for which take was selected of the two options. mserror = mean squared error.

To ensure that after the midpoint adjustment of each of the best takes reasonable intelligibility slope functions were still being achieved; they were compiled into a new list for the same test setup. These new versions were then presented twice at each SNR to a further 3 participants with normal hearing. These were 3 females with a mean age of 34.33, and an age range of 23 – 52. Rather than presenting both takes of each digit recording twice, the chosen take for each digit was now presented four times to these participants, thereby improving the reliability of these measurements.

This new data was averaged with the previous data set, and was used to fit intelligibility functions as described above.

	Psychometric data				Recording		Fitted psychometric function parameters							Adjustments
Position 1	**-13**	**-10.5**	**-8**	**-5.5**	**Take**	**ID**	**Lmid**	**s**	**SImax**	**A**	**Slope at midpoint:**	**mserror**	**Goal:**	**-11.3 dB**
0	0.375	0.708	1.000	1.000	1	1-0(1)	-11.7 dB	1.360	1	9	16.34 %/dB	0.0011		-0.4 dB
1	0.333	0.667	0.958	0.958	2	1-1(2)	-11.4 dB	1.419	1	9	15.66 %/dB	0.0006		-0.1 dB
2	0.500	0.583	0.833	0.875	2	1-2(2)	-11.8 dB	3.287	1	9	6.76 %/dB	0.0016		-0.5 dB
3	0.167	0.333	0.833	0.958	1	1-3(1)	-9.4 dB	1.034	1	9	21.50 %/dB	0.0004		1.9 dB
5	0.458	0.625	0.792	0.917	1	1-5(1)	-11.6 dB	2.927	1	9	7.59 %/dB	0.0001		-0.3 dB
6	0.375	0.625	0.917	1.000	1	1-6(1)	-11.3 dB	1.697	1	9	13.10 %/dB	0.0008		0.0 dB
7	0.417	0.667	0.792	0.833	1	1-7(1)	-11.5 dB	3.192	1	9	6.96 %/dB	0.0014		-0.2 dB
8	0.208	0.792	0.958	0.958	1	1-8(1)	-11.4 dB	0.780	1	9	28.49 %/dB	0.0007		-0.1 dB
9	0.333	0.667	0.917	1.000	1	1-9(1)	-11.3 dB	1.491	1	9	14.91 %/dB	0.0001		0.0 dB
Position 2	**-13**	**-10.5**	**-8**	**-5.5**										
0	0.375	0.583	0.917	0.917	2	2-0(2)	-11.1 dB	1.899	1	9	11.70 %/dB	0.0019		0.2 dB
1	0.375	0.750	0.958	1.000	1	2-1(1)	-11.8 dB	1.353	1	9	16.43 %/dB	0.0000		-0.5 dB
2	0.417	0.458	0.750	0.750	1	2-2(1)	-10.0 dB	3.883	1	9	5.72 %/dB	0.0034		1.3 dB
3	0.125	0.750	0.917	1.000	1	2-3(1)	-11.0 dB	0.572	1	9	38.88 %/dB	0.0016		0.3 dB
5	0.458	0.750	0.958	0.917	1	2-5(1)	-12.2 dB	1.772	1	9	12.54 %/dB	0.0013		-0.9 dB
6	0.542	0.875	1.000	1.000	1	2-6(1)	-12.9 dB	1.283	1	9	17.31 %/dB	0.0001		-1.6 dB
7	0.167	0.417	0.875	0.917	1	2-7(1)	-9.8 dB	1.123	1	9	19.79 %/dB	0.0012		1.5 dB
8	0.167	0.667	0.875	0.875	1	2-8(1)	-10.8 dB	1.110	1	9	20.02 %/dB	0.0057		0.5 dB
9	0.417	0.750	0.917	1.000	2	2-9(2)	-12.0 dB	1.616	1	9	13.75 %/dB	0.0001		-0.7 dB
Position 3	**-13**	**-10.5**	**-8**	**-5.5**										
0	0.083	0.292	0.667	0.875	1	3-0(1)	-8.6 dB	1.367	1	9	16.26 %/dB	0.0014		2.7 dB
1	0.583	0.750	1.000	0.958	1	3-1(1)	-13.1 dB	2.085	1	9	10.66 %/dB	0.0021		-1.8 dB
2	0.333	0.708	0.958	0.958	2	3-2(2)	-11.5 dB	1.341	1	9	16.57 %/dB	0.0004		-0.2 dB
3	0.292	0.625	0.833	0.958	1	3-3(1)	-10.8 dB	1.736	1	9	12.80 %/dB	0.0004		0.5 dB
5	0.417	0.542	0.917	0.917	1	3-5(1)	-11.1 dB	2.121	1	9	10.48 %/dB	0.0039		0.2 dB
6	0.458	0.875	0.875	0.958	2	3-6(2)	-12.5 dB	1.393	1	9	15.95 %/dB	0.0030		-1.2 dB
7	0.167	0.708	0.958	0.958	1	3-7(1)	-11.0 dB	0.767	1	9	28.98 %/dB	0.0006		0.3 dB
8	0.417	0.708	0.833	0.917	2	3-8(2)	-11.7 dB	2.355	1	9	9.44 %/dB	0.0007		-0.4 dB
9	0.208	0.583	0.875	1.000	1	3-9(1)	-10.6 dB	1.261	1	9	17.62 %/dB	0.0003		0.7 dB
						Mean:	-11.3 dB						**Mean:**	0.0 dB
						Standard Deviation:	1.0 dB						**Mean adjustment magnitude:**	0.7 dB
													Max adjustment:	2.7 dB

Table 5: The values for the best takes, and the adjustments made to the midpoint of each. SImax – speech intelligibility maximum, mserror = mean squared error

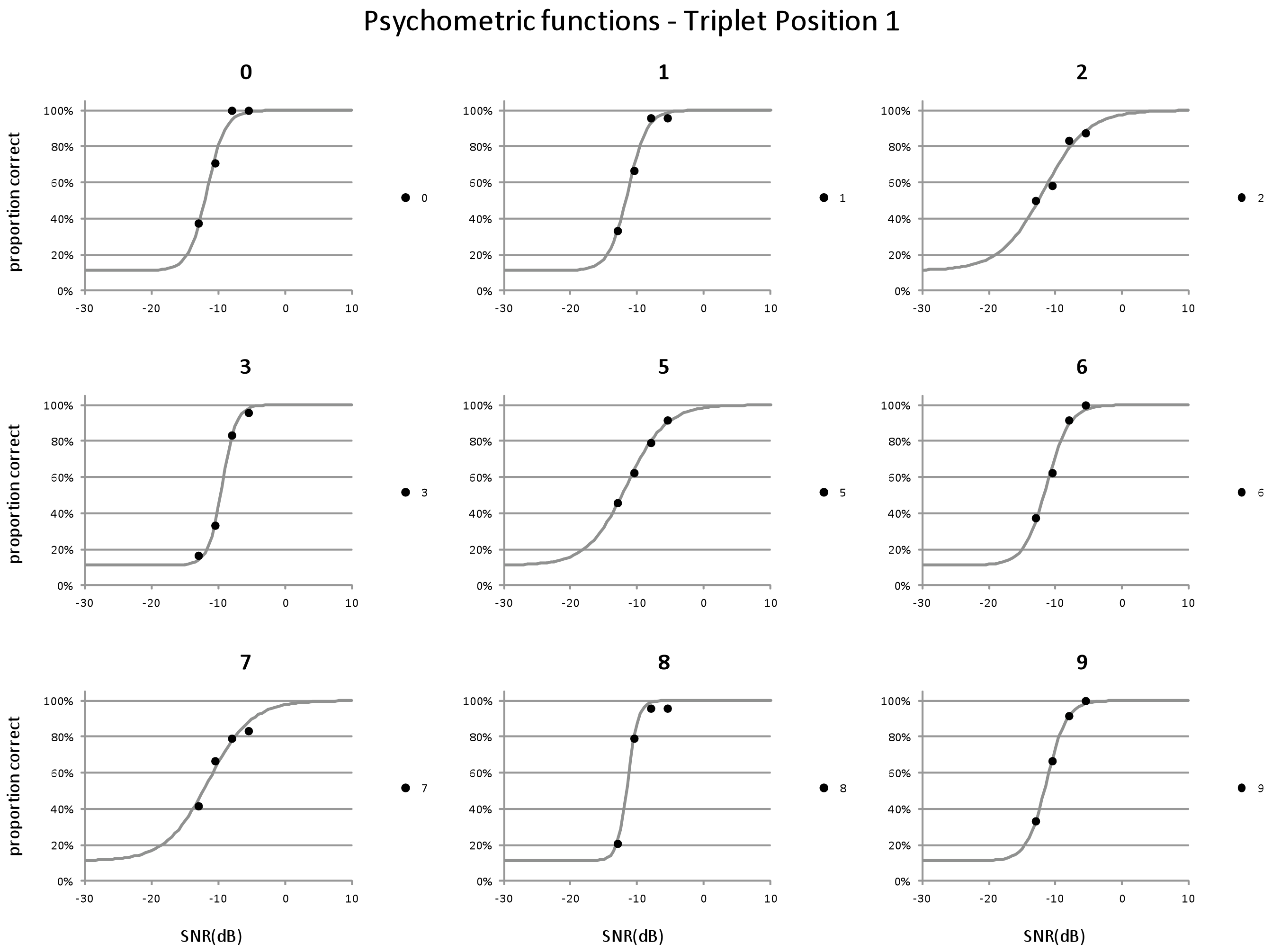


Figure 7: Psychometric data and fitted intelligibility functions for the digits accepted into Triplet Position 1.

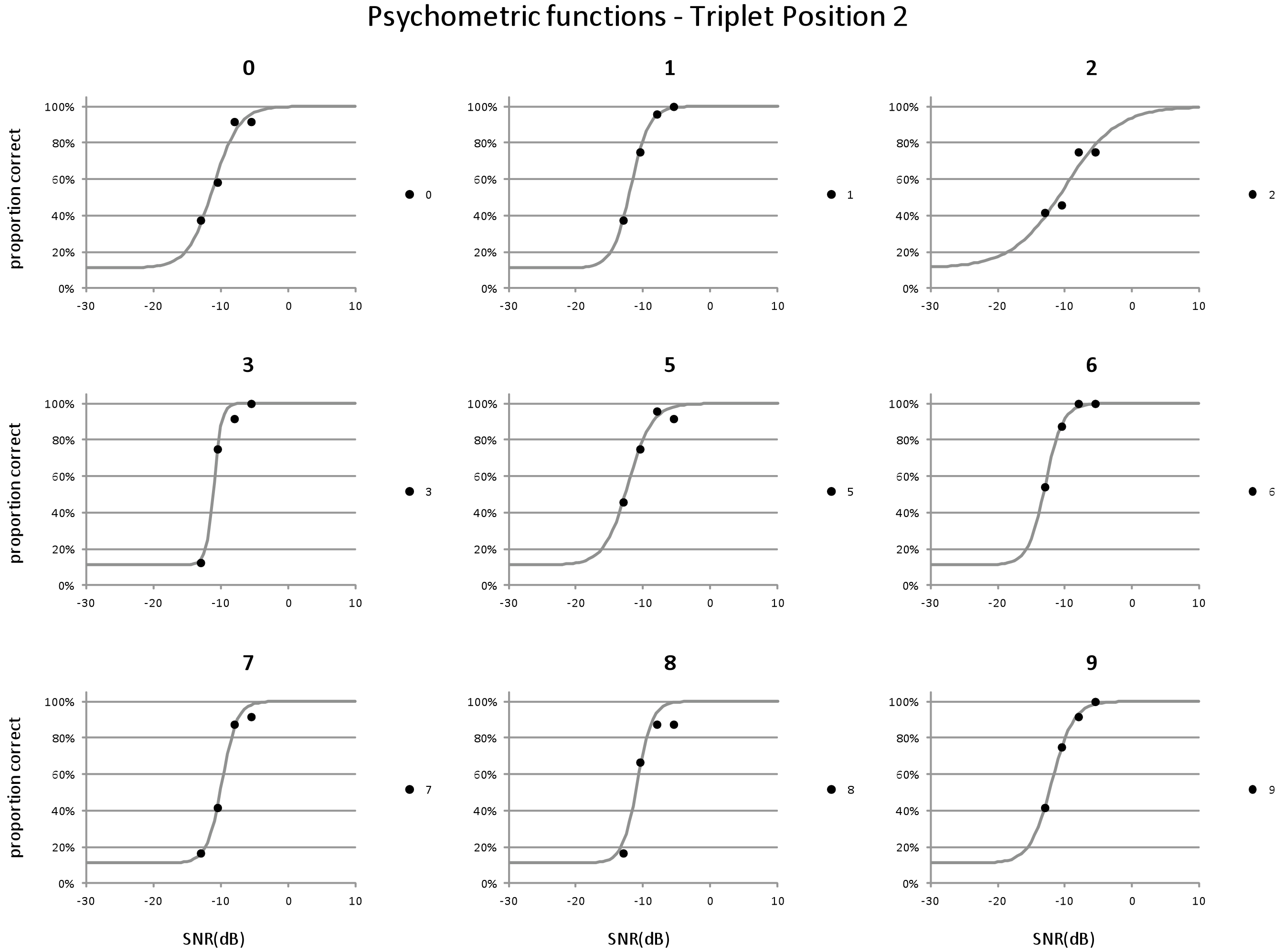


Figure 8: Psychometric data and fitted intelligibility functions for the digits accepted into Triplet Position 2.

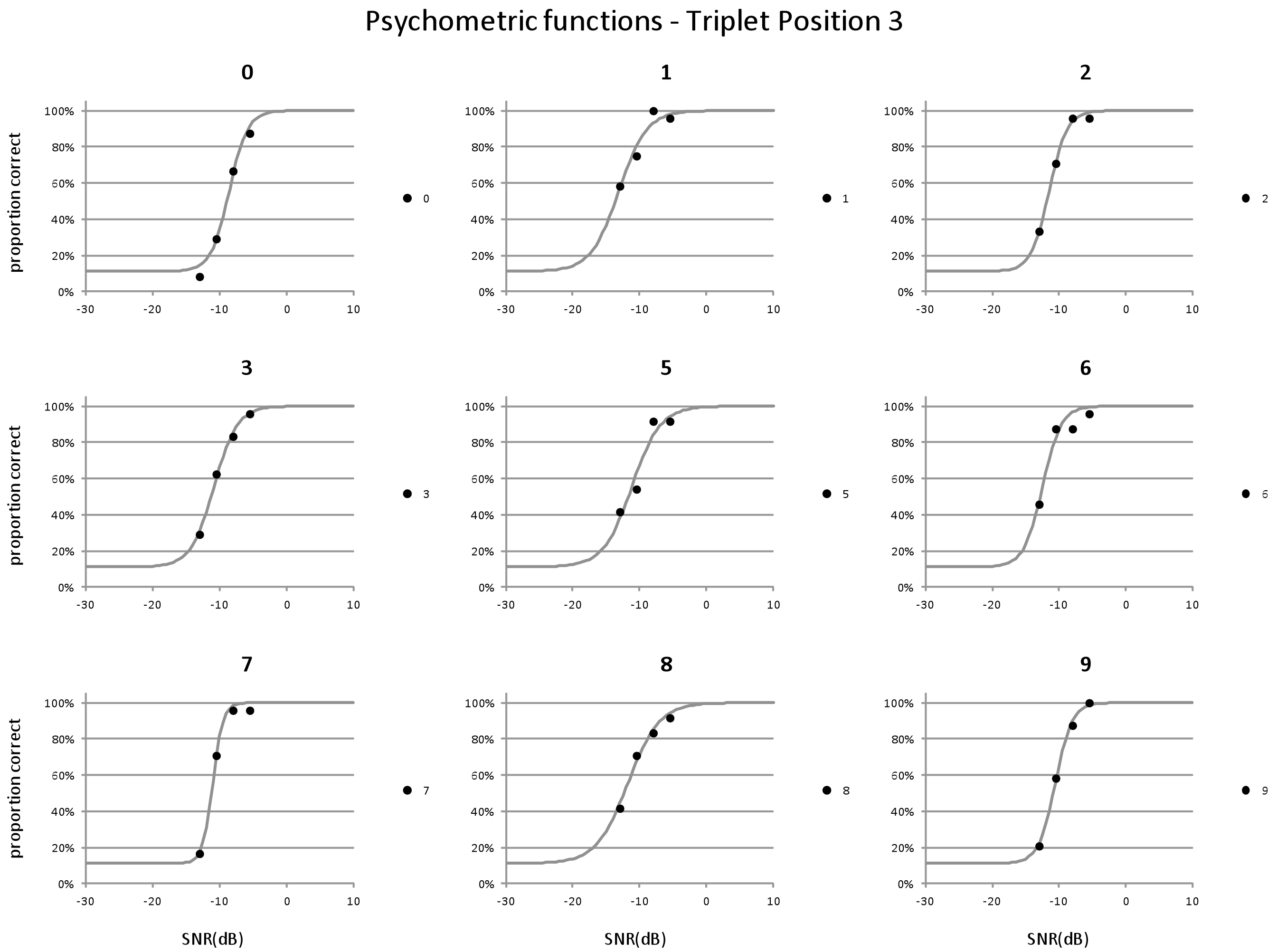


Figure 9: Psychometric data and fitted intelligibility functions for the digits accepted into Triplet Position 3.

The levels of each digit recording were then adjusted so that their midpoints were equal to the mean of the pre-normalisation average midpoint for these digits (-11.3 dB SNR), in order to make each digit in each position equally difficult. Individual selection and adjustment of the level of each digit has previously been shown to give the steepest possible slope for triplet intelligibility when the intelligibility curves for each digit in the triplet are closely matched. The SRT value (50% intelligibility), or midpoint, is most commonly used as a point to adjust the digit curves. As the intelligibility curve for a triplet is derived from the curves for each contributing single digit, the slope of the triplet intelligibility function is maximised when the midpoints for each single digit's curve is the same. As shown in Table 5, the mean magnitude of the adjustments was 0.7 dB, and the maximum required adjustment was 2.7 dB.

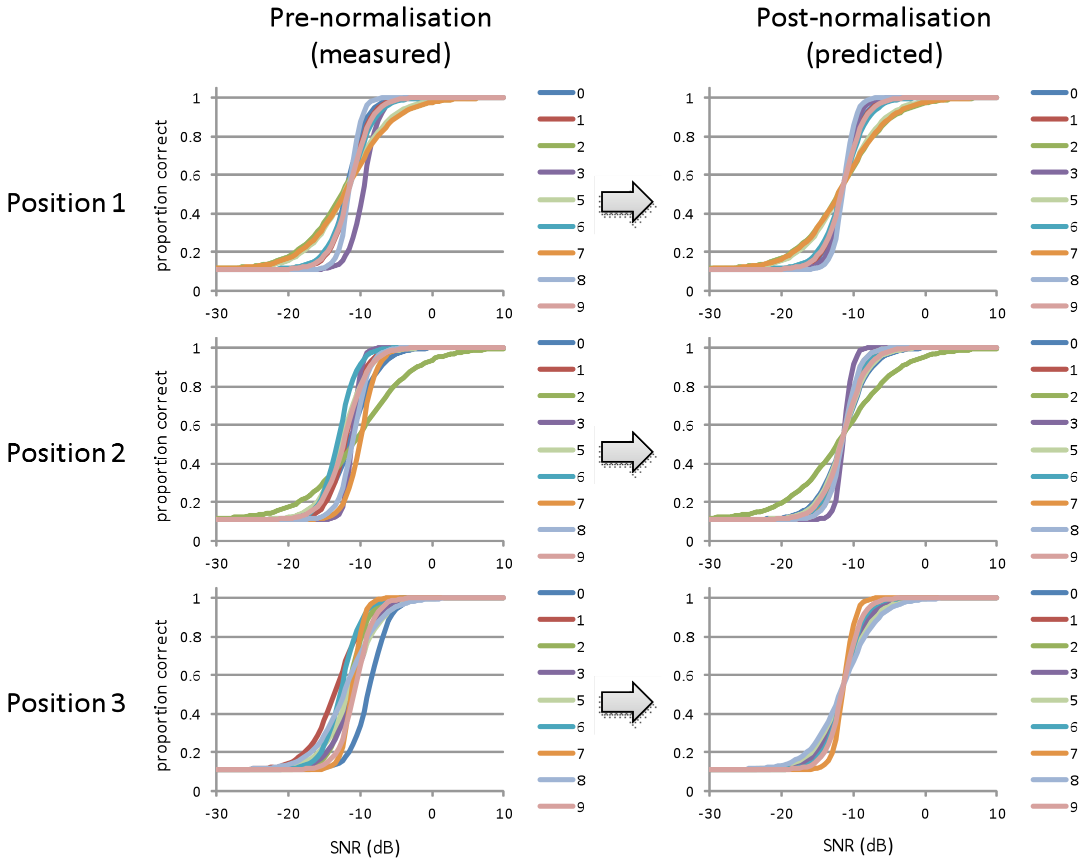


Figure 10: The predicted effect of adjusting the level of each digit to achieve a consistent L_{mid}.

2.7 Triplet Lists

2.7.1 Generation from Normalised Digits

As described above, the second phase examined the test material on both a triplet and list level. The best take of each digit at each position (the steepest intelligibility slope), as determined in the first normalisation phase, was used to create 8 lists of 27 triplets using the software written for this purpose by Dr Greg O'Beirne. The software first generated several thousand lists of 27 triplets according to the rules described for the Digit Normalisation phase (Chapter 2.3). As each list of 27 triplets contained three presentations of the same nine digits in each position, every list had the same mean calculated triplet slope of 15.77%/dB. The deciding factor was therefore the homogeneity of the lists (i.e. the smallest range of calculated triplet slopes).

Two sets of lists were produced: One set of ten lists, where triplets were able to appear in multiple lists, and one set of eight lists, where no triplet was repeated across the lists. The spread of slopes of the two lists is shown in Figure 11 below.

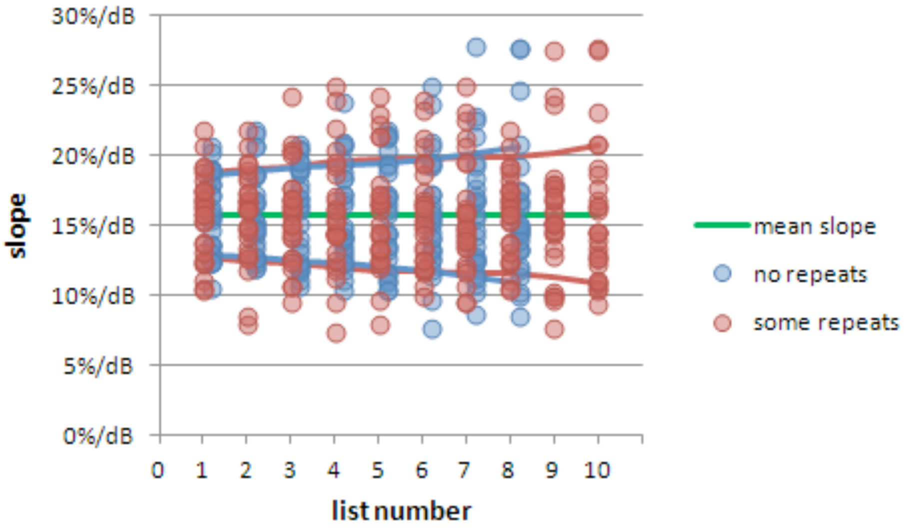


Figure 11: Spread of the slopes of the two lists produced.

Because the two sets of lists were fairly similar in terms of the spread of slopes, it was decided to proceed with the set of eight lists with no repeated triplets.

The range of the slopes included over the 8 chosen lists is shown in Table 6.

	List								
Slope Values	1	2	3	4	5	6	7	8	Mean Value
Mean	15.77	15.77	15.77	15.77	15.77	15.77	15.77	15.77	15.77
Std Dev	2.84	3.34	3.06	3.50	3.73	4.47	4.05	4.83	3.73
Steepest	20.62	20.86	21.83	23.86	21.89	27.89	24.91	27.74	23.7
Shallowest	10.50	10.62	11.95	10.39	10.43	8.71	7.72	8.50	9.86
Range	10.12	10.24	9.88	13.47	11.46	19.18	7.19	19.24	13.84

Table 6: Descriptive data for the eight lists generated from the normalised digit triplets. All value units are %/dB.

Previous comparisons performed during the development of the New Zealand English DTT showed that combining normalised digits into triplets resulted in a reduced variance for the psychometric functions generated for each digit in each position of the triplet (e.g. see Figures 10 and 12 of S. King (2011)). With this in mind, as well as the difficulties with achieving adequate participant numbers, this step was not considered necessary to perform for the Māori language version.

2.8 Pilot Test

The final phase of this study required participants representing a range of sensorineural hearing losses to test the accuracy of the developed DTT for correctly identifying the known hearing status of the individuals. This stage was not completed within the available time for the study, and as such, only the results of two participants were obtained. The participant with normal hearing levels, NHM010, was a 28 year old male, and the second participant, HTM042, was a 54 year old male with a mild to moderate high frequency (4000 – 8000 Hz) sensorineural hearing loss.

For this phase, the test was presented to each ear separately as well as binaurally. Participants were included on the basis of their knowledge of the Māori language, and the degree of their hearing loss. Recruitment aimed for representation of a range of hearing losses, as far as was possible. Participants' ears with conductive hearing losses were not tested. This was due to the difference in difficulty that a speech in noise test generally presents for people with conductive hearing losses, as compared to those with sensorineural losses (Smits & Houtgast, 2005; Yueh et al., 2003) who have more trouble because of the deterioration of the cochlea tuning that accompanies sensorineural hearing function decline (Dillon, 2001).

If audiometric results obtained within the last six months were not provided, participants underwent diagnostic audiometric testing using standard pure-tone audiological procedures, where both air conduction and bone conduction thresholds were determined for the frequencies 250 – 8000 Hz. The testing procedure followed similar methods outlined in steps 1-5 for the Digit Normalisation phase (Chapter 2.6.1), except that thresholds were sought at each frequency, as opposed to screening to 10 dB HL, and bone conduction followed air conduction testing at the frequencies where hearing loss was found.

2.8.1 Procedure for hearing testing in the Pilot Test

1. Participants were seated inside a soundproof booth in the Audiology clinics in the Department of Communication Disorders. They were asked for their age, and their own view of their hearing.

2. Using an otoscope, the insides of participants' ears were inspected for general health, presence of any wax and eardrum status.

3. Participants were instructed to press a response button whenever they heard a tone in either ear, regardless of how soft it sounded. They were then fitted with Telephonics TDH-50P headphones (serial number SN C7088) through which they would hear the tones.

4. The door to the soundproof booth was closed, and participants could view the tester through a double-paned glass window.

5. The test commenced, using a Grason-Stadler GSI 61 audiometer. Air conduction thresholds were determined across the frequencies 250, 500, 1000, 2000, 4000 and 8000 Hz, using the modified Hughson-Westlake method for audiological testing (Carhart & Jerger, 1959). Both ears were tested across all frequencies.

6. Where applicable, bone conduction testing was also implemented to determine the nature of any hearing loss found. Masking techniques were used whenever required to prevent contribution from the better hearing ear.

7. Participants were verbally informed of the results of the testing.

Those with confirmed sensorineural hearing loss in one ear or both were asked to listen to the digit lists that had been created and established as equivalent in the previous phases of this study. Only ears with confirmed hearing loss were used. The same instructions for what the participants would hear and how they should respond was given as for the digit normalisation phase, as outlined in steps 1 and 2 for the Digit Normalisation phase (Chapter 2.6.2).

Each participant listened to three different triplet lists in three different ways: with their right ear only, with their left ear only and binaurally. Lists were randomly selected for the participants, as was the order for how they were listening. Each list took approximately 5 minutes (300 ± 80 s) to perform.

Participants performed the test in the same manner as outlined in the normalisation methods above (Chapter 2.6.2), however the test had an adaptive method for this phase. From a starting SNR of +2 dB, the SNR decreased by 2 dB with every correct answer and increased by 2 dB with each incorrect answer. The test terminated after the 27 stimulus presentations, and the threshold level was calculated as the average of the final 20 SNRs.

2.8.2 Pilot Test Results

Two participants were recruited for the pilot test stage before the time available for data collection finished. The first participant, HTM042 had a high frequency hearing loss (see Table 7 below), and the second participant, NHM010 had normal hearing levels.

	Frequency (Hz)							
	0.25	0.5	1	2	3	4	6	8
Right Ear Threshold (dB HL)	10	0	5	5	15	25	35	45
Left Ear Threshold (dB HL)	15	10	10	10	15	35	35	35

Table 7: Threshold levels in dB HL for participant HTM042's ears

The adaptive tracks for each participant's performance in the three listening conditions (binaural or each ear separately) are shown in the graphs in Figure 12. The estimated SNR thresholds generated from this data are shown in Table 8.

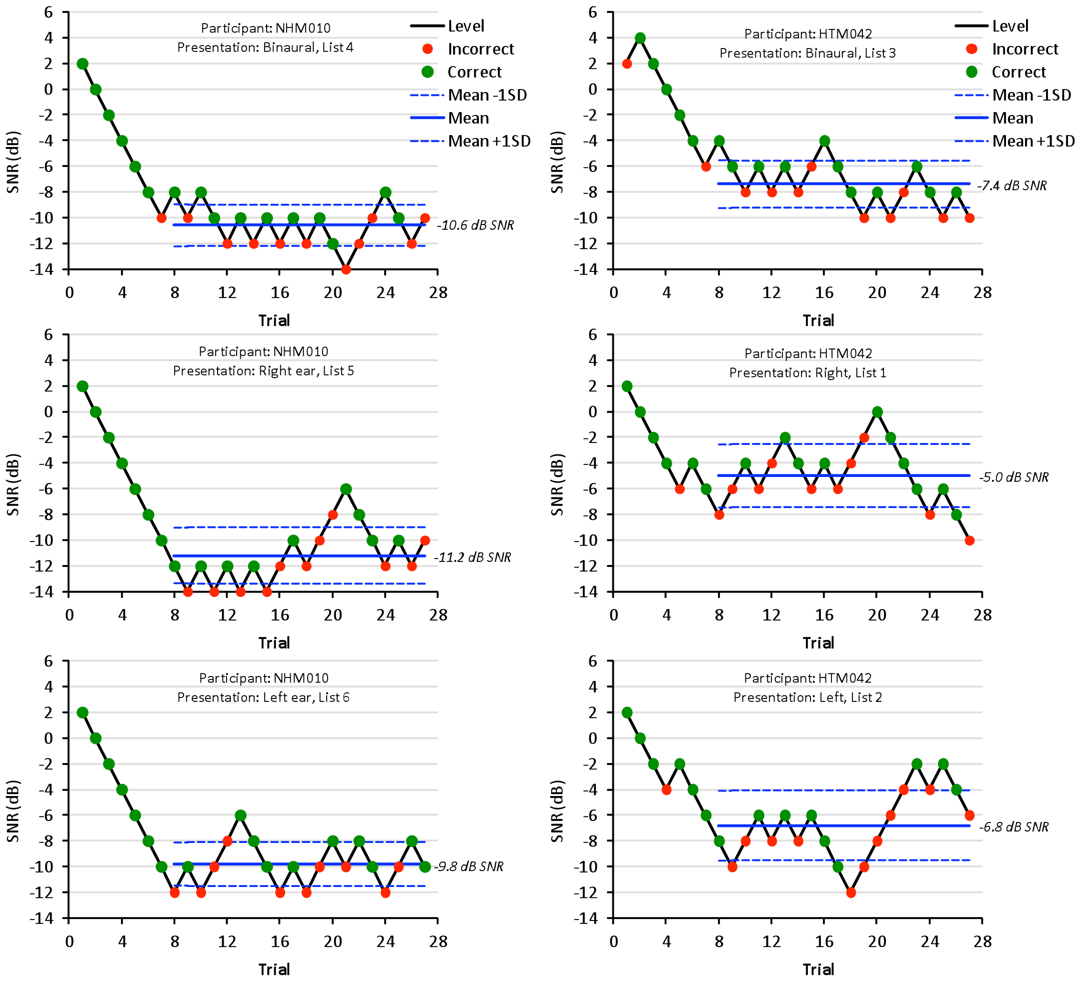


Figure 12: Adaptive tracks for the two participants tested during the pilot phase, NHM010 and HTM042. SD = standard deviation.

Estimated digit SRT (dB SNR)			
Participant	Right Ear	Left Ear	Binaural
HTM042	-5.0	-6.8	-7.4
NHM010	-11.2	-9.8	-10.6

Table 8: The estimated SNR threshold for the two participants in the pilot test phase.

3 Discussion

3.1 Level of Hearing Loss Identified with DTT

When the inner ear suffers a loss of sensitivity through the death or damage of its hair cells, higher intensities of sound are required to stimulate the compromised regions of the basilar membrane. With increased sound intensity, however, the displacement of the basilar membrane is increased, so that portions adjacent to the targeted region are also stimulated by its movement, and this results in a broader tuning of the cochlea (Dillon, 2001) (Snik & Horst, 1991).

Snik and Horst (1991) found that hearing impaired listeners experienced a greater change in frequency resolution than could be accounted for by increased sound intensity alone. Work by Nelson (1991) showed that in 78% of a sample of 18 hearing impaired listeners, frequency resolution became abnormal when hearing thresholds were 40 dB HL or greater at the probe frequency used. As frequency selectivity contributes to speech discrimination (Snik & Horst, 1991), the difficulty that people with hearing loss experience understanding speech in noise is likely due to the loss of fine frequency resolution that helps separate out the speech signal.

A study by Davis, Smith, Ferguson, Stephens, and Gianopoulos (2007) suggested that aiming hearing screening at those with hearing thresholds 35 dB HL or higher is the most effective approach, as people with at least this amount of impairment were more inclined to accept amplification and rehabilitation intervention than those with better threshold levels (Davis et al., 2007). SIN test performance cannot be predicted well by pure-tone audiometric thresholds (Kramer et al., 1998). An automatic SIN test, such as the DTT, can thus only be set to identify a particular range of SNR levels where an individual’s SRT is determined as being equal to a pre-programmed qualitative response, such as the “good”, “poor”, or “insufficient” result possibilities used in this DTT. It can therefore be expected that each of the three responses will apply to listeners with a range of pure-tone threshold levels.

There are limitations for identifying hearing loss using the DTT. When presented over the telephone, which is a frequency-limiting transducer, then hearing loss present outside of the frequencies able to be heard through the telephone handset will not be identified (Jansen et al., 2010). This may mean individuals with isolated higher frequency hearing loss will receive a better result than they would have otherwise. Furthermore, the DTT is a SIN test. Pure-tone audiometry results are not very good predictors of speech recognition scores in both normal hearing and hearing impaired populations (Jansen et al., 2010; McArdle et al., 2005). Instead, non-linear weighted functions of pure-tone audiometric thresholds, such as the American National Standards Institute Speech Intelligibility Index (ANSI, 1997) are more suitable for this purpose.

One might expect that is would be more useful to compare results from an established SIN test to those achieved by the DTT using the same population – however, previous work during the development to the New Zealand English DTT (S. King, 2011) showed there was no useful correlation between the results for the HINT (Hearing in Noise Test). Additionally, comparing results between an English language SIN test to the Māori language DTT would present its own issues of validity for cross-language comparisons.

3.2 Considerations During Normalisation and Pilot Test

3.2.1 Inattention

The role of inattentiveness during normalisation of the Māori language DTT must be considered, computer simulations performed by Green (1995) indicated that lapses in attention can introduce a strong bias to the threshold estimate. This results in a lapse rate that is assumed to be higher than zero in most psychophysical measures, where incorrect guesses are input regardless of the SNR. Given that the forced-choice DTT presents a closed set of the digits 0-9 as options, the chance of randomly selecting the correct digit by chance is $^1/_9$ for the digit normalisation task. However, this reduces to $^1/_9$ x $^1/_9$ x $^1/_9$ = $^1/_{729}$ for the pilot test, which is scored on a whole-triplet basis.

Each list available for the pilot test phase of the DTT contains 27 triplets, with the final time of the test averaging around five minutes. By keeping the test short, lapses of concentration are minimised, with these parameters having been successfully used in other international tests. During the Māori language DTT normalisation and the pilot test, the listener submitted their answer each time to begin the next presentation. In an effort to minimise the contribution of fatigue, the listener was made aware that if they wished to take a short break during the test, they could refrain from pressing the enter key until they were ready to proceed.

3.2.2 Impact of age

As the current project stands there is not enough of an age range for speculation as to how age may impact on the results generated, the majority of the current participants are between 18 and 25 years old. Souza and Turner (1994) compared young and elderly listeners matched for hearing impairments, and concluded that differences in performance for monosyllabic speech understanding in steady and modulated background noise was correlated with having sensorineural hearing loss and not age-specific factors. However, other research has suggested that elderly adults generally do worse in SIN tests than young adults, presumably due to an age-related decline in either general cognitive function or specifically the processing component of the auditory system, making it more difficult for older adults to discriminate between speech and noise (Pichora-Fuller, Schneider, & Daneman, 1995).

3.3 Binaural Advantage

This DTT will eventually be made available for use through both the internet and the telephone. This presents an immediate listening difference – when accessing the test via the internet, individuals listening with speakers will be using both ears; compared to only one ear when using headphones or the telephone – the more popular method for Smits et. al.'s Dutch language DTT (Smits et al., 2006), unless the individual switches the device to a speakerphone mode.

Listening binaurally is known to give a release from masking when listening to speech in noisy conditions. It is attributed to the auditory system comparing sound signals between both ears, recognising the noise component and reducing its masking effect (Newton, 2009, pp. 288-290). With understanding speech in noise being the most common complaint of people with hearing impairment (Kramer et al., 1998), this advantage is a common reason for audiologists to recommend a bilateral fitting when both of an individual's ears have hearing loss, particularly when the loss is greater than mild – communication in noisy places should be considerably easier with two hearing aids rather than one, or none (Dillon, 2001, p. 382). In the DTT, however, this binaural advantage is not available, as there is no spatial or temporal separation between the noise and speech signals. Smits, et al.'s (2006) investigation into the results from listeners using an internet version versus those using a monaural telephone for the Dutch language DTT did not find a large difference between the average group results, with the internet participants achieving SNR levels 0.1 dB lower than that of the telephone participants..

Furthermore, Smits, Kapteyn, and Houtgast (2004) found that there was a high correlation (0.866) between their telephone DTT SRT_n results and those achieved by their listeners performing a reference SIN sentence test via headphones that was developed by Plomp and Mimpen (1979), who used headphones during their normalisations. The Smits group suggested that this was because both tests were normalised using the same listening method (telephone or headphones, respectively) as was used for the testing. Normalisations had thus optimised the material for minimal measurement error when the same transducers used in the development of the test were used for performing it (Smits et al., 2004).

Listeners that have an asymmetric hearing loss could achieve different results between testing with the internet version using headphones or speakers, and testing via the telephone. For example, as noted during the development of the NZE DTT, where a listener with an asymmetric hearing loss achieved a "good" result for the test when listening binaurally, but had they performed the test monaurally via the telephone, they would have been expected to pass the test in the better ear, but achieve a "poor" or "insufficient" result for the worse ear (S. King, 2011). Depending on an individual's auditory processing ability in the better ear, an asymmetric mild-moderate hearing loss could achieve the normal-hearing result of "good". The internet version of the DTT has the option to choose to perform the test monaurally via headphones, or binaurally if only speakers are available. Should the listener choose to perform the test with speakers, a clear message explaining that the results will be indicative of the better ear only would avoid users potentially misinterpreting a "good" result as ruling out the presence of hearing loss in either ear.

3.4 Digit and Noise Material

The intelligibility curve for the triplets used in the testing were derived from the curves for each contributing single digit, so that the slope of the triplet intelligibility function would be maximised when the midpoints for each single digit's curve was adjusted to be the same (see the end of Chapter 2.6.3). However, a theoretical model by Smits and Houtgast (2006) suggested that a maximum slope at the 50% level for a triplet is more likely to be generated when adjusting the contributing single digit curves to converge at the 79.4% intelligibility point (Jansen et al., 2010). This would thus be the preferred method to use in future projects in order to maximise the midpoint slope for triplets.

The noise used in the DTT experiments presented here was a constant signal at 65 dB SPL, and had the same spectral components as the speech material. This was generated through superimposing the digit recordings 10,000 times using an automated process.

In 1991, Nelson suggested that frequency resolution may only become abnormal when hearing impairment is greater than 40 dB HL, or a moderate hearing loss (Nelson, 1991). Results from Lorenzi, Gilbert, Carn, Garnier and Moore (2006) indicated that a "moderate sensorineural hearing loss causes a dramatic deterioration in the ability to use temporal fine structure (of sound) for speech perception" (p. 18867). A study by Smits and Houtgast (2007) compared the effects of using different noise types as speech maskers in digits-in-noise tests. They used interrupted noise, with 16 Hz or 32 Hz modulations, as well as continuous noise and tested 42 ears with either normal or elevated hearing levels. They found a 16 Hz interrupted speech-shaped noise resulted in a much more efficient achievement of the speech reception threshold (SRT_n) by creating a higher spread of results between the normal hearing and hearing impaired ears compared to both the continuous noise and the 32 Hz modulated noise (Smits & Houtgast, 2007). Testing by Lorenzi et al. (2006) suggested that this loss of ability contributed to the reduced capability of the participants with hearing impairments to use the dips in the background noise to garner more speech information. As listeners with hearing impairments cannot use this advantage, using modulated noise allows an increased efficiency for identifying normal hearing listeners by exploiting this difference (Lorenzi et al., 2006).

Future studies for the DTT could take advantage of this increased efficiency by interrupting the speech noise used periodically with a 16 Hz square wave.

3.5 Auditory Processing Difficulties and Speech in Noise Tests

Auditory processing difficulties describe the problems a person with normal peripheral hearing has when in challenging listening situations. Due to central auditory process differences, a person with auditory processing difficulties can struggle to separate a speech signal they want to listen to from background or competing sound stimuli, such as music or background chatter. These individuals, when free from any other ear injury or disease, perform well on standard audiological testing in quiet conditions, but if tested with a speech-in-noise (SIN) test, they will perform poorer than expected for someone with determined normal hearing thresholds (Lagace, Jutras, & Gagne, 2010).

The Māori language DTT normalised in this study is a SIN test. This is because this condition is an area that people with hearing loss find more difficult (Kramer et al., 1998; McArdle & Wilson, 2009), and will be useful for identifying those with hearing loss that do well in quiet situations, but struggle in more challenging environments (Smits et al., 2004). It also allows testing to take place with uncalibrated transducers, such as telephone handsets. To develop this screening test, the normalisation stage required volunteers that had normal hearing. As only standard audiological screening was performed using pure-tone testing in quiet, there is a possibility of volunteers having auditory processing difficulties, with the prevalence of auditory processing disorder (APD) estimated as 0.5-1% in the population (Hind et al., 2011). This would affect their results when listening to the speech in noise DTT, and they would not be representing normal listening behaviour as assumed. To this end, the results of each volunteer who was determined as having normal peripheral hearing needed to be examined for unexpectedly poor performance, which could indicate an auditory processing difficulty when listening to speech in background noise. Equally, this may raise concern that people with auditory processing difficulties may be falsely identified by the released test as having hearing loss. While this may occur, further diagnostic testing, if sought, would rule out a peripheral hearing loss, and the audiologist could then perform SIN tests, or refer for auditory processing testing if they are aware that the person is seeking consultation due to an “insufficient” or “poor” result in a screening SIN test. The individual could benefit by learning about products and strategies that could aid them in everyday situations that they struggle in due to auditory processing difficulties, when they may have previously rationalised their difficulties as being due to not being a good listener, or easily distracted.

3.6 DTT via internet and Telephone

This test will eventually be available by both the telephone and internet. Before this can be realised, another study will need to be performed for listeners undertaking the DTT using the telephone, as well as a sufficient pilot test being completed for the current test. It may be expected that there would be more variables for the real-world testing via the internet than with a telephone, as listeners could use in-ear phones, headphones, external computer speakers, or built-in computer speakers (Jansen et al., 2010). Indeed, Smits, et al. (2006) found that for the Dutch DTT, after age and gender adjustments were made, whether headphones or computer speakers were used for performing the test by internet gave a larger difference in the average SNR threshold achieved than the difference between using the telephone and the internet test: internet participants achieved SNR thresholds that were 0.1 dB lower than the telephone participants, compared to an average SNR threshold 1.1 dB higher when internet participants used speakers compared to those who used headphones. Better results were thus obtained using headphones, as the sound does not undergo reflection and ambient noise is reduced to a degree. The Dutch DTT instructions strongly advised that headphones were used for the internet version, however their data revealed only 31% complied with this. Whether this was due to not owning headphones, or low motivation by these participants to optimise the test conditions for themselves (Smits et al., 2006), it cannot be determined, or controlled for in the test's real-world application.

3.7 Delays and Difficulties Completing the Māori Language DTT

Sluggish participant recruitment and delays caused by ongoing seismic activity in the Canterbury region both contributed to the pilot test not being completed to a satisfactory extent. More participants are required to generate meaningful results that would allow us to establish whether the Māori language DTT is accurate and efficient for use by both normal hearing and hearing impaired listeners. Given that we followed established normalisation procedures (Smits et al., 2004) and the NZE DTT (S. King, 2011) was developed in a very similar way (excluding the second normalisation phase on a triplet level), we would expect that this DTT would meet expectations of identifying people with hearing loss. Without actual results, however, regrettably this test is not yet ready for real-world application. There may be unforeseen issues from using disyllabic words as opposed to the monosyllabic digits used in the NZE DTT, as this may be more demanding on elderly listeners' working memories. However, with six of the ten Polish digits (0-9) disyllabic, the Polish language DTT used both disyllabic and monosyllabic digits. Concerning this mix of digit syllabic content, there were no reported issues of participants being more likely to correctly answer either type of digit, as long as the proportions of each were kept similar during testing (Ozimek et al., 2009). This suggests no increased difficulty for participants recalling disyllabic digits compared to monosyllabic digits, and accordingly, no issues arising from this are expected for the Māori language digit test.

3.7.1 Ethics Approval Process

The ethics approval process was slow due to continuing earthquake activity throughout the year. For example, the initial submission to the University of Canterbury Ethics Committee was hampered by the near two-month suspension of teaching and use of assigned buildings on campus for the Communication Disorders department staff and students following the February 22nd event. A second example of was the submission of a Māori Consultation form to the Māori Research Advisory Group on the 10th of June 2011. Following the significant aftershocks experienced on the 15th of June, the University closed for several days, and the Advisory Group meeting due to be held that week was cancelled, with the next occurring a month later, at which approval was granted. These delays meant that advertising for the study could not begin until halfway through the academic year.

3.7.2 Participant Recruitment

This study was not exclusively looking for ethnically Māori participants; however, a large amount of advertising was directed to these communities, as the proportion of Māori language speakers was presumed to be higher than the general population. The difficulties with recruitment experienced during this project may be due to reasons suggested for healthcare-seeking behaviours of the Māori population, which are known to be at lower rates than the non-Māori population in New Zealand (Baxter, 2002; Ellison-Loschmann & Pearce, 2006). Baxter (2002) suggested a lack of cultural appropriateness as a barrier for Māori accessing health services. The way the service is provided and how it interacts with the attitudes of the person receiving the service may lead to an uncomfortable relationship between both individuals and health services. A common approach for government services is to follow a generic method to cater for as many individuals as possible, however, this risks legitimising ignoring ethnic differences (Baxter, 2002). Differences for effective recruitment between the Māori and non-Māori populations may have been a factor for low participant numbers.

J. King, Maclagan, Harlow, Keegan and Watson (2011) discuss a common preference amongst Māori for face-to-face, personal interaction, with the use of posters for advertising being much less effective than when used for recruitment in the general population. In their study, they found most of their participants were friends, or friends of friends, agreeing with the suggestion that for Māori, recruitment via direct approach is more effective, though this can risk discomfort for those approached. Due to the unique research opportunities presented by the Māori culture and communities, there are concerns that Māori may be seen as research subjects instead of participants, and this has resulted in the implementation of consultation whenever research involves the Māori communities and/or culture. Ideally, there is a Māori researcher involved in the running of the study, or non-Māori researchers who already have familiarity and ties to the Māori community.

Advertising for the study was also carried out in the form of short speeches to Māori language classes at the University of Canterbury. While modestly successful, with four participants recruited, further success was likely precluded by the impending University examination and summer holiday period. Approaching these classes earlier in the teaching term may have proved more successful, and would have been a more effective use of this resource.

3.8 Conclusions

Hearing loss is a significant physical impairment that is often under-recognised, under-treated and under-reported (Dalton et al., 2003). Most commonly, hearing loss is due to damage or deterioration of the hair cells in the inner ear – a sensorineural hearing loss (Dillon, 2001). The fine-tuning of the hearing organ becomes broader, reducing frequency resolution (Dillon, 2001; Snik & Horst, 1991). Functionally, this means that it is more challenging to separate speech signals from noise, and hearing in noisy situations is the most common complaint of people with hearing loss (Kramer et al., 1998). As well as being a sensory deficiency, there are associations of hearing loss with detrimental psychological effects, such as paranoia, depression and anxiety (Weinstein, 2009).

There are many barriers to seeking help for hearing impairment, including financial concerns (Schoen et al., 2002), geographical isolation, and being unaware that there is any hearing loss (Yueh et al., 2003). Furthermore, there is a stigma surrounding hearing aids, and many older adults accept hearing loss as merely a part of “getting old” (Wallhagen, 2010).

Hearing loss in New Zealand has an estimated prevalence of 10.3%, with the Māori population affected at higher rates than the non-Māori population (Greville, 2005). Producing the DTT in both New Zealand English and Māori will ideally appeal to a wider population with people being able to perform the test in the language they are most comfortable with.

Hearing screening is a useful tool that can assess whether further investigation into an individual’s hearing is necessary (Yueh et al., 2003). A hearing screening test which does not require travel or significant financial input could help overcome barriers commonly obstructing healthcare access, and using an adaptive SIN test prevents subjective assessment of someone’s hearing ability, as may occur with questionnaires (Smits, 2005).

From the efforts of this study, the normalisation stage for the Māori language DTT is complete. The next stage of the project – a pilot test that will include a sufficient number of participants to ensure that the test accurately identifies hearing loss over a range of different hearing patterns – is now underway.

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4 Appendices

4.1 University of Canterbury Human Ethics Committee Approval

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UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2011/36

12 August 2011

Christa Murray
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Christa

The Human Ethics Committee advises that your research proposal "Maori version of the New Zealand hearing screening test" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 5 August 2011.

Best wishes for your project.

Yours sincerely

Michael Grimshaw
Chair
University of Canterbury Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. www.canterbury.ac.nz

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4.2 Māori Research Advisory Group Approval

Māori Research Advisory Group

Tel: +64 3 364 3050 Fax: + 64 364 2950
Email: john.pirker@canterbury.ac.nz

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Monday 15 July 2011

Tēnā koe Christa,

Re: Māori Version of the New Zealand Hearing Screening Test

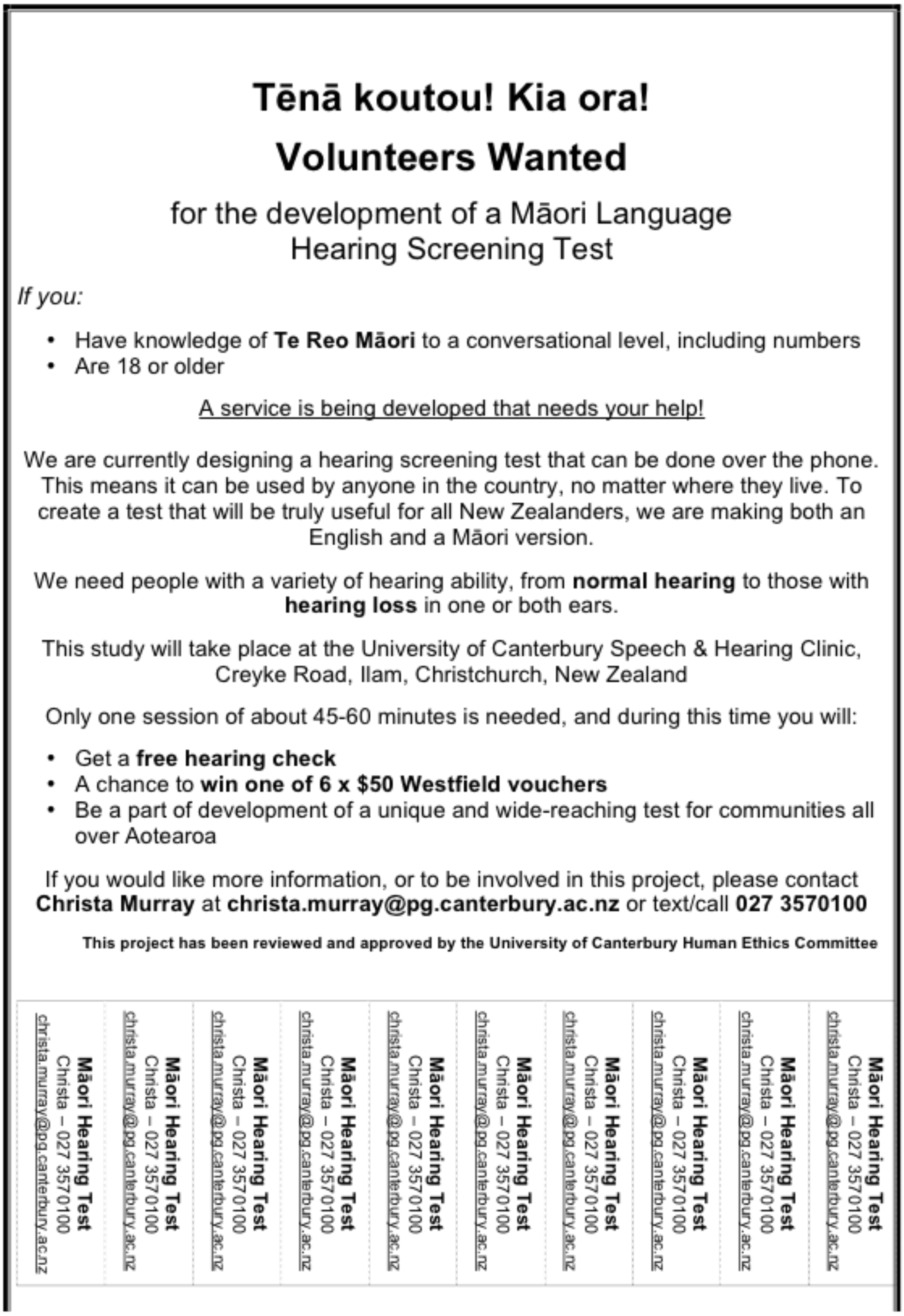
Ngā mihi ō te wā ki a koe, te kairangahau ō tēnei kaupapa whakahirahira. Ngā mihi hoki ki a koe i runga i tēnei te whakawhitiwhiti korero ki te whakapakari te mahi.

Thank you for your consultation form. The Māori Research Advisory Group (MRAG) is happy to support your research. We appreciate the efforts that you and your research team have go to in developing a Māori language component for the New Zealand Hearing Screening Test. We also acknowledge that your work may provide for greater acessability for such tests by using the phone or internet. In the long term, we hope that your research will result in the early identification and reduction of hearing deficiencies in Māori. We wish you all the best in your research and look forward to seeing a summary of the results once your research has been completed.

Nāku noa (Yours sincerely)

Dr John Pirker
Māori Research Advisory Group
University of Canterbury

4.3 Advertisement Flyer



Tēnā koutou! Kia ora!

Volunteers Wanted

for the development of a Māori Language
Hearing Screening Test

If you:

- Have knowledge of **Te Reo Māori** to a conversational level, including numbers
- Are 18 or older

A service is being developed that needs your help!

We are currently designing a hearing screening test that can be done over the phone. This means it can be used by anyone in the country, no matter where they live. To create a test that will be truly useful for all New Zealanders, we are making both an English and a Māori version.

We need people with a variety of hearing ability, from **normal hearing** to those with **hearing loss** in one or both ears.

This study will take place at the University of Canterbury Speech & Hearing Clinic, Creyke Road, Ilam, Christchurch, New Zealand

Only one session of about 45-60 minutes is needed, and during this time you will:

- Get a **free hearing check**
- A chance to **win one of 6 x $50 Westfield vouchers**
- Be a part of development of a unique and wide-reaching test for communities all over Aotearoa

If you would like more information, or to be involved in this project, please contact **Christa Murray** at **christa.murray@pg.canterbury.ac.nz** or text/call **027 3570100**

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee

Māori Hearing Test
Christa – 027 3570100
christa.murray@pg.canterbury.ac.nz

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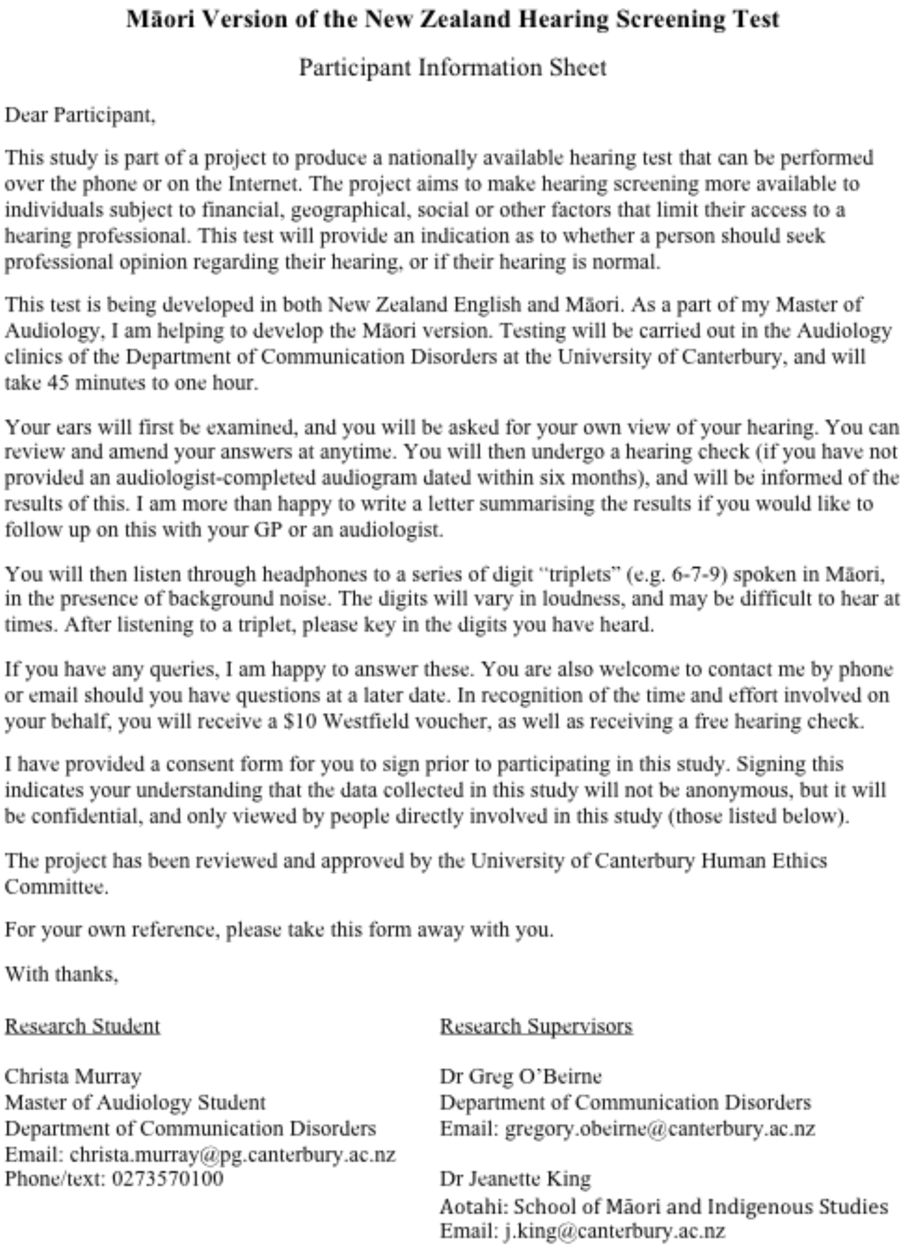
christa.murray@pg.canterbury.ac.nz

4.4 Participant Information and Consent Form



Māori Version of the New Zealand Hearing Screening Test

Participant Information Sheet

Dear Participant,

This study is part of a project to produce a nationally available hearing test that can be performed over the phone or on the Internet. The project aims to make hearing screening more available to individuals subject to financial, geographical, social or other factors that limit their access to a hearing professional. This test will provide an indication as to whether a person should seek professional opinion regarding their hearing, or if their hearing is normal.

This test is being developed in both New Zealand English and Māori. As a part of my Master of Audiology, I am helping to develop the Māori version. Testing will be carried out in the Audiology clinics of the Department of Communication Disorders at the University of Canterbury, and will take 45 minutes to one hour.

Your ears will first be examined, and you will be asked for your own view of your hearing. You can review and amend your answers at anytime. You will then undergo a hearing check (if you have not provided an audiologist-completed audiogram dated within six months), and will be informed of the results of this. I am more than happy to write a letter summarising the results if you would like to follow up on this with your GP or an audiologist.

You will then listen through headphones to a series of digit "triplets" (e.g. 6-7-9) spoken in Māori, in the presence of background noise. The digits will vary in loudness, and may be difficult to hear at times. After listening to a triplet, please key in the digits you have heard.

If you have any queries, I am happy to answer these. You are also welcome to contact me by phone or email should you have questions at a later date. In recognition of the time and effort involved on your behalf, you will receive a $10 Westfield voucher, as well as receiving a free hearing check.

I have provided a consent form for you to sign prior to participating in this study. Signing this indicates your understanding that the data collected in this study will not be anonymous, but it will be confidential, and only viewed by people directly involved in this study (those listed below).

The project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

For your own reference, please take this form away with you.

With thanks,

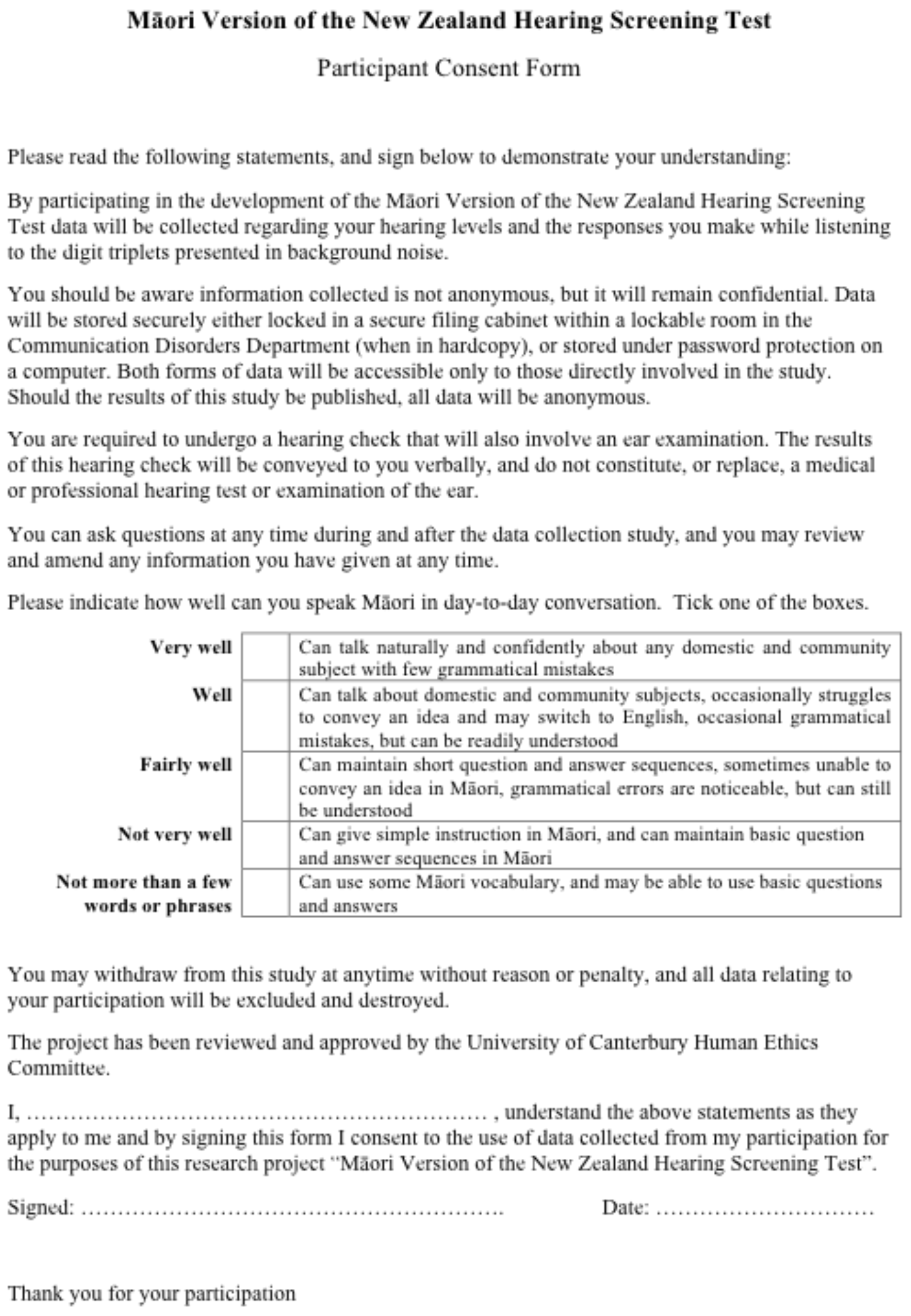
Research Student

Christa Murray
Master of Audiology Student
Department of Communication Disorders
Email: christa.murray@pg.canterbury.ac.nz
Phone/text: 0273570100

Research Supervisors

Dr Greg O'Beirne
Department of Communication Disorders
Email: gregory.obeirne@canterbury.ac.nz

Dr Jeanette King
Aotahi: School of Māori and Indigenous Studies
Email: j.king@canterbury.ac.nz



Māori Version of the New Zealand Hearing Screening Test

Participant Consent Form

Please read the following statements, and sign below to demonstrate your understanding:

By participating in the development of the Māori Version of the New Zealand Hearing Screening Test data will be collected regarding your hearing levels and the responses you make while listening to the digit triplets presented in background noise.

You should be aware information collected is not anonymous, but it will remain confidential. Data will be stored securely either locked in a secure filing cabinet within a lockable room in the Communication Disorders Department (when in hardcopy), or stored under password protection on a computer. Both forms of data will be accessible only to those directly involved in the study. Should the results of this study be published, all data will be anonymous.

You are required to undergo a hearing check that will also involve an ear examination. The results of this hearing check will be conveyed to you verbally, and do not constitute, or replace, a medical or professional hearing test or examination of the ear.

You can ask questions at any time during and after the data collection study, and you may review and amend any information you have given at any time.

Please indicate how well can you speak Māori in day-to-day conversation. Tick one of the boxes.

Very well	☐	Can talk naturally and confidently about any domestic and community subject with few grammatical mistakes
Well	☐	Can talk about domestic and community subjects, occasionally struggles to convey an idea and may switch to English, occasional grammatical mistakes, but can be readily understood
Fairly well	☐	Can maintain short question and answer sequences, sometimes unable to convey an idea in Māori, grammatical errors are noticeable, but can still be understood
Not very well	☐	Can give simple instruction in Māori, and can maintain basic question and answer sequences in Māori
Not more than a few words or phrases	☐	Can use some Māori vocabulary, and may be able to use basic questions and answers

You may withdraw from this study at anytime without reason or penalty, and all data relating to your participation will be excluded and destroyed.

The project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

I, ………………………………………………………… , understand the above statements as they apply to me and by signing this form I consent to the use of data collected from my participation for the purposes of this research project "Māori Version of the New Zealand Hearing Screening Test".

Signed: …………………………………………………….   Date: …………………………

Thank you for your participation