DEVELOPMENT OF A MONOSYLLABIC ADAPTIVE SPEECH TEST FOR THE IDENTIFICATION OF CENTRAL AUDITORY PROCESSING DISORDER

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Abstract

Auditory processing is the ability of the brain to manipulate and utilise the neural output of the ear based on the frequency, intensity, and temporal features of the incoming acoustic signal. An auditory processing disorder (APD) is a deficiency in this ability. One category of tests that examine auditory processing ability are the various versions of the “filtered words test” (FWT), whereby a monaural, low-redundancy speech sample is distorted by using filtering to modify its frequency content.

Due to the richness of the neural pathways in the auditory system and the redundancy of acoustic information in spoken language, a normal listener is able to recognize speech even when parts of the signal are missing, whereas this ability is often impaired in listeners with APD. One limitation of the various versions of the FWT is that they are carried out using a constant level of low-pass filtering (e.g. a corner frequency of 1000 Hz), which is prone to ceiling and floor effects. The purpose of this study was to counter these effects by modifying the FWT to use a computer-based adaptive procedure, to improve the sensitivity of the test over its constant-level counterparts.

The University of Canterbury Monosyllabic Adaptive Speech Test (UC MAST) was performed on 23 normal adults, and 32 normal children (7 to 11 years of age). The child participants also underwent the SCAN-C test for APD in Children - Revised.
Findings indicated a significant maturational effect on the UC MAST. Adult participants performed significantly better on the UC MAST in comparison to the child participants. In addition, adult participants performed the UC MAST more reliably than their younger counterparts. No correlation was found between performance on the UC MAST and SCAN-C test. The development of the UC MAST is discussed and the clinical implications of the findings are explored.
Acknowledgements

“Laughter and tears are both responses to frustration and exhaustion...........
I myself prefer to laugh, since there is less cleaning up to do afterward.”

Kurt Vonnegut, Jr. (American Writer, b. 1922).

Are there many things in this world more difficult, frustrating and exhausting than writing a thesis? Indeed there are many!

For starters – how about living with someone who is trying to complete one? Or being the friend of someone who continually cancels plans at the last minute because they had to work on their never-ending thesis? Or try the role of the luckless parents - who fly across the ditch (twice) to help one celebrate the achievement, only to find out on arrival that the cause for celebration is far from over? And last but certainly not least, consider being the student’s primary supervisor – a role requiring patience, understanding, and the self-control not to strangle the student when he’s failed to meet his deadline for the umpteenth time!

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Finally, thank you to my wonderfully loyal Wheaten Terriers. To Floyd - who not only provided endless opportunities for procrastination at a moment’s notice but sat under my desk keeping my feet warm as I worked into the early hours of the night to make up for them. To Molly - who arrived late in the piece, for keeping Floyd distracted so that I no longer could be - allowing me to finally finish this epic event.
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List of Abbreviations

*Units*

dB – decibel
HL – hearing level
Hz – Hertz

*Terms*

APD: Auditory Processing Disorder
ASHA - American-Speech-Language-Hearing Association
CANS – Central Auditory Nervous System
CAPD: Central Auditory Processing Disorder
FWT: filtered words test
LPF – Low-pass Filter
NU-CHIPS - North-western University Children’s Perception of Speech
SCAN-C: A Screening Test for Auditory Processing Disorders in Children – Revised
UC MAST: University of Canterbury Monosyllabic Adaptive Speech Test
UoCSHC – University of Canterbury Speech and Hearing Clinic
WRS – Word recognition Score
Chapter One

INTRODUCTION
General Introduction

There has been a great deal of focus on how best to assess and determine the nature of Auditory Processing Disorder (APD) (Singer et al., 1998; Schow et al., 2000). One category of APD assessments are monaural, low-redundancy speech tests known as low-pass filtered speech tests. This category of test is designed to remove many of the high frequency speech sounds required for speech discrimination. Due to the richness of the neural pathways in the auditory system and the redundancy of acoustic information in spoken language, a normal listener is able to recognize speech even when parts of the signal are missing, whereas this ability is often impaired in listeners with APD (Bellis, 2003). Reduced performance on the various versions of this test may therefore indicate the presence of an APD (Costello, 1977; Dempsey, 1977; Martin & Clark, 1977; White, 1977; Willeford, 1977).

A collection of filtered words tests have been made available in the commercial market (Flowers et al., 1970; Willeford, 1977; Keith, 1986, 2000c). Like any constant-method test, these versions of the low-pass filtered words test are vulnerable to ceiling and floor effects (Farrer & Keith, 1981). As a result, a filtering condition that clearly differentiates children with and without APD is the most appropriate. Consequently, the different versions of these tests have varied greatly in their cut-off filter frequency (Farrer & Keith, 1981; Rintelmann, 1985), i.e., the corner frequencies at which the low-pass filter is implemented. Accordingly, the efficacy of this category of tests has been questioned (W. R. Hodgson, 1966; Martin & Clark, 1977).

The aim of this study was to improve the various versions of the filtered words tests by replacing constant-level filtering with an adaptive testing protocol, thereby removing the dilemma associated with choosing the most appropriate corner
frequency and with it, the ceiling and floor effects that potentially affect the efficacy of the test.

**Historical perspective**

Interest in the diagnosis, treatment, and management of APDs has been discussed in the literature for over fifty years (Bocca *et al.*, 1954; Myklebust, 1954). The notion that some individuals may have difficulty in processing auditory information despite normal hearing sensitivity was first proposed by Helmer Myklebust (1954) who stressed the importance of clinically evaluating central auditory processes, particularly in children suffering from communicative disorders (Myklebust, 1954; J. Jerger, 1998; Wertz *et al.*, 2002).

Initially, testing concentrated on establishing sites of lesion. Bocca and his colleagues (1954; Bocca *et al.*, 1955) were the first to report on the auditory difficulties described by patients with unilateral temporal lobe disorders, in spite of normal peripheral auditory findings. These Italian scientists described patients that presented as though they had a hearing loss and concluded that unilateral lesions of the central auditory nervous system (CANS) could impair auditory processing ability (Musiek & Baran, 1987).

Less than a decade later, Kimura (1961a; Kimura, 1961b) administered a dichotic speech test to a group of subjects with unilateral temporal lobe lesions. Kimura (1961a; Kimura, 1961b) reported reduced recognition scores in the ear contralateral to the temporal lobe lesion, as well as ipsilateral deficits in subjects with left hemisphere lesions.

In the time since these first findings, researchers have endeavoured to gain a more thorough comprehension of the processes underlying these difficulties. Further research (Milner, 1962; Milner *et al.*, 1965) has shown subjects with temporal lobe
lesions to have difficulty in the perception of tonal sequences. A number of researchers (Musiek et al., 1980) have shown that lesions in the corpus callosum affect the interhemispheric transfer of auditory information and Jerger and Jerger (1974) reported deficits in the ability to understand speech due to lesions in the brainstem.

Ultimately, many of these site-of-lesion tests (tests used to determine the presence of a lesion in the auditory system) were applied to children showing similar symptoms to those of adults with CANS lesions and by the late 1960’s, the term “auditory processing disorder” began to emerge (Martin & Clark, 1977; Willeford, 1977). Over the past few decades, considerable focus has been placed on the identification of APDs in children, as research began to show a link between auditory processing ability and academic achievement (Cruickshank, 1981; Lasky & Katz, 1983; Hurley & Singer, 1985).

However, from its initial description to the present, the concept of APDs has been challenged and criticised on a number of fronts. From a review of the literature, it appears that every aspect of APD is immersed in confusion and debate. Debate exists over the terminology used to describe the disorder and the underlying functions that are affected by the disorder. There is a lack of a clear definition of what constitutes APD, leading to the question of whether APD truly exists. Debate exists over the most appropriate tests to diagnose the disorder and whether it can be diagnosed as a separate identity at all (Rees, 1973; Burd & Fisher, 1986; Humes et al., 1992; Chermak et al., 1997; Amos & Humes, 1998). The following section attempts to clarify APD by providing a brief overview of the nature of the disorder.
Terminology

Historically, APD has been known by a variety of names including King Kopetzky Syndrome and Obscure Auditory Dysfunction (Lin & Staeker, 2006). Until recently, the term “central auditory processing disorder” (CAPD) has been used to describe the disorder, however there has been a great deal of controversy regarding the inclusion of the term “central” in the title (ASHA, 2005).

Support for the use of the term “central” is based on the concept that most definitions of the disorder focus on the central auditory nervous system (CANS). Therefore, it has been argued the term “central” more clearly distinguishes the VIII nerve, brainstem and cortical areas as the anatomical site of dysfunction, as opposed to the peripheral auditory system (ASHA, 2005). However, according to Jerger and Musiek (2000), “central” and “processing” are redundant words and based on their recommendations, the term “auditory processing disorder” (APD) has been used in the remainder of this paper for the purposes of clarity.

Normal Auditory Processing

The CANS is responsible for the manipulation and utilisation of neural information from the auditory periphery – a process known as auditory processing (Katz, 1992). In essence, auditory processing is the auditory system mechanism responsible for “what we do with what we hear” (Lasky & Katz, 1983).

As our understanding of the neuroanatomy and neurophysiology of the CANS has grown, the complexities of auditory processing have slowly been deciphered. Between the arrival of speech to the ear canal and our understanding of its meaning, a great deal of mechanical and neurobiological processes intervene (Musiek & Lamb, 1994; Musiek & Chermak, 1997).
The underlying processes that contribute to these functions are complex and debate exists whether auditory processing consists purely of bottom-up (sensory encoding) processes, top-down (cognitive, language and other higher-order functions) processes or a combination of both processes working together (McFarland & Cacace, 1995; Musiek & Chermak, 1997; Friel-Patti, 1999; Bellis, 2003).

Bottom-up processing is based on the properties of the sound being the main determinants of higher-level representations and constructions. The auditory ascending pathway consists of the brainstem, the cerebellum and the cerebrum. Evaluation is based on the different levels of the CANS and according to McFarland & Cacace (1995), testing can separate auditory processing from the higher non-auditory factors, such as attention, cognition, language, learning and memory. Top-down processing is based on a networking of information in the nervous system that consists of an integration of sound, meaning and intention and involves more than just the auditory pathway (Friel-Patti, 1999).

The information processing theory suggests it is a combination of bottom-up and top-down processes that determine an individual’s ability to process auditory information (Bellis, 2003). Based on this theory, the relative contribution of bottom-up or top-down processes is determined by the listening environment. In the case of an individual listening to degraded speech - such as stimuli from a filtered words test, there is a greater emphasis placed on top-down processing (Chermak et al., 1997).

As an acoustic signal travels up the auditory pathway, the signal is not simply relayed from structure to structure. Each level of the ascending pathway contributes a substantial amount of auditory processing that allows extraction and enhancement of the important parts of the signal (Bellis, 2003). For a complete list of the underlying
processes that make up auditory processing, the reader is referred to Heasley (1974) for his in-depth review of the subject.

**Auditory Processing Disorder**

Rees (1973) questioned whether APD was a definite disorder and argued that speech understanding is purely a result of top-down processes such as higher cognitive processing, with minimal reliance on auditory processing for understanding speech stimuli. However, Jerger (1998) suggested that three lines of converging evidence support APD as a bottom-up auditory perceptual disorder:

i) Over 30 years of mounting audiological evidence that links subjects who have a known site of lesion (e.g., tumour) on their central auditory pathway to their symptoms of APD, supporting the concept that individuals with APD may have a problem in their CNS;

ii) Over 10 years of accrued in-depth studies of specific auditory perceptual difficulties in subjects whose only complaint is an inability to hear well in adverse listening conditions; and,

iii) Growing evidence that the unique hearing difficulties of the elderly may be due to age-related changes in the central rather than peripheral auditory system.
The confusion surrounding APD led ASHA\textsuperscript{1} to seek a clear definition of what constitutes the disorder, by assembling a task force (ASHA, 1996) who defined APD as difficulties in the processing of auditory information in the central nervous system as demonstrated by poor performance in one or more of the following skills:

- Sound localization and lateralization;
- Auditory discrimination;
- Auditory pattern recognition;
- Temporal aspects of audition, including:
  - Temporal integration;
  - Temporal discrimination (e.g., temporal gap detection);
  - Temporal ordering; and,
  - Temporal masking.
- Auditory performance in competing acoustic signals (including dichotic listening); and,
- Auditory performance with degraded acoustic signals (ASHA, 2005b).

\textbf{Symptoms of APD}

It is estimated that APD is prevalent in two to three percent of children (Musiek & Chermak, 1997). The overall impression of a child with APD may be one who appears generally inattentive, “not with it”, fidgety, absent-minded, or impatient (Bellis, 2003).

\textsuperscript{1} ASHA (American Speech-Language-Hearing Association).
Additional behaviours that surface as a result of listening problems may provide an inkling to the presence of APD, including:

- Responding inconsistently to auditory stimuli, e.g. sometimes a child will successfully follow a set of instructions, yet other times they becomes confused with the same task;
- Displaying a relatively short attention span or tiring easily when faced with extensive or complex listening activities;
- Becoming overly distracted by both auditory and visual stimuli and unable to ignore background noise as irrelevant;
- Requesting information to be repeated more often than other children; and,
- Displaying problems with short-term and long-term memory skills, such as counting, reciting the alphabet or recalling a home phone number (Chermak & Musiek, 1977; Katz, 1992; Bellis, 2003).

**Cause of APD**

For the majority of individuals, the cause of their APD is unknown (Bellis, 2003). Factors include neurological disorders, genetic disorders, a significant history of persistent otitis media, neuromorphological abnormality (misplaced or mis-shaped neural cells), maturational delay or a combination of the above (Bellis, 2003). Chermak and Musiek (1997) suggest that neuromorphological disorder underlies APD in 65 to 70% of diagnosed cases.

APD can result from dysfunction of the processes specific to the auditory modality, but it can also co-exist with a more global processing deficit involving a variety of sensory systems, such as language, attention and memory deficits (Baran & Musiek, 1999). Therefore, a differential diagnosis may be difficult to achieve as an APD may be associated with conditions such as dyslexia, attention deficit disorder,
autism spectrum disorder, speech and language impairment, pervasive developmental disorder, or developmental delay (J. Jerger & Musiek, 2000). Consequently, identification of APD is extremely challenging, and as described below, its assessment is critical.

**APD Assessment**

Assessment of the CANS and identification of APD is critical for a number of reasons (Musiek *et al.*, 1990):

- To determine if medical aspects of the disorder exist which are neurologically based, and which may require medical treatment;
- To increase awareness of the presence of the disorder, which can truly affect a child’s ability to learn;
- To reduce the wasted effort and frustration incurred by parents as they search for help and understanding of the child’s difficulties;
- To minimise the psychological factors affecting the child and family as a result of not knowing the cause of the child’s problem;
- To enable insightful educational planning to be instigated, once a problem is confirmed and defined; and,
- To determine interventions, which are helpful to the student’s learning process, including the use of FM assistive listening devices, auditory training, compensatory strategies, and environmental modifications.

As described above, there are many symptoms of APD, but no single test is sufficient in scope to adequately challenge the variety of functions required by the CANS in different listening situations (Dempsey, 1983). Therefore, utilisation of a number of tests is the key to identification of APD – however, it is neither feasible, nor advisable to administer all tests to all patients (Baran & Musiek, 1999). For that
reason, it is recommended that a comprehensive APD test battery incorporating a variety of tests be used to assess each of the different processes mentioned above (Katz, 1992; Musiek & Lamb, 1994; American Speech-Language-Hearing Association, 1996).

These tests generally include:

- Temporal processing tests: assess the ability of the auditory system to analyse acoustic events over time;
- Dichotic speech tests: assess the ability of the auditory system to binaurally integrate and/or binaurally separate simultaneously presented speech stimuli;
- Monaural, low-redundancy speech tests: assess the ability of the auditory system to analyse speech with reduced intelligibility;
- Binaural interaction tests: assess the binaural processes that underlie the timing, lateralization, and localisation of acoustic stimuli;
- Electrophysiological tests: assess the synchronous responses generated by the CANS in response to a wide array of acoustic events; and,
- Electro-acoustic tests: assess the acoustic signals recorded from within the ear canal that are in response to acoustic stimuli or generated spontaneously.

**Interpreting Test Results**

Various approaches are used to interpret the results of the above tests. The majority of APD tests are designed around norm-based comparisons. For this method of interpretation, the performance of the subject being tested is compared to the performance of a group of normal individuals who have completed the same test as part of a normative study. Deriving a mean performance score for a specific age group and then subtracting two standard deviations from their mean to produce a cut-off score usually establish criterion
for “performance within the normal range”. The individual being tested is required to obtain a score higher than the age appropriate cut-off score to be considered normal. If a subject yields a test result that is below two standard deviations from the mean on two different tests for APD, then they are considered at risk for the disorder.

**Monaural, low-redundancy speech tests**

The current research project focuses on just one of the above categories of APD assessment; the monaural, low-redundancy speech test. Research has shown that complex stimuli such as speech are the most effective for the evaluation of APD (Bocca et al., 1954; J. Jerger, 1964; Goetzinger, 1972). Listeners with APD will typically perform quite well when auditory stimuli are presented in ideal listening environments. Although they may have normal peripheral hearing, they exhibit unusual difficulty in the processing of auditory stimuli presented in unfavourable acoustic conditions (Martin & Clark, 1977).

In speech communication, the term redundancy relates to excess information that assists with word identification. As the name implies, a monaural, low-redundancy speech test involves testing one ear with speech stimuli - in which the acoustical content has been degraded to reduce its redundancy. Degradation of speech stimuli may be achieved through the modification of the frequency, intensity, or temporal characteristics of the undistorted signal. Specifically, this investigation will be based on a category of monaural, low-redundancy speech tests known as filtered words tests, in which speech stimuli is distorted by using filtering to modify its frequency content.
**Origins of the various filtered speech tests**

The use of filtered speech in central auditory testing had its clinical origins in the 1950’s when as mentioned earlier, Bocca and his colleagues (1954; Bocca et al., 1955) reported on the impaired auditory processing ability of patients with unilateral temporal lobe disorders. This team of Italian physicians was the first to recognise that peripheral auditory testing was insensitive to the auditory difficulties reported by patients with temporal lobe lesions. This was due to the highly complex processing abilities of the CANS (intrinsic redundancy) combined with the tonal and high fidelity speech signals used as test stimuli (extrinsic redundancy).

In persons with normal peripheral auditory systems, this combined redundancy provides sufficient information so that the CANS is not taxed and normal test results are generated (Rintelmann, 1985; Medwetsky, 2002). As a result, the task of identifying lesions in the CANS required an auditory test that negated the combined redundancy of both the auditory system and the acoustic signal (Medwetsky, 2002). Specifically, Bocca and his colleagues (1954; Bocca et al., 1955) theorised that disorders of the CANS could be detected by degrading the acoustic properties of the speech stimuli through low-pass filtering to reduce the redundancy of the test material.

For the majority of patients tested, the results revealed poorer discrimination of speech that had been filtered with cut-off frequencies above 500 Hz (Bocca et al., 1954). Further investigations have supported the use of various versions of the filtered speech tests in the identification of cortical lesions (Bocca, 1958; J. Jerger, 1960a, 1960b; Calearo & Antonelli, 1963; W. Hodgson, 1967; Lynn & Gilroy, 1972, 1977; Musiek & Lamb, 1994).
The distortions in the linguistic signal decrease the internal redundancy, stressing the CANS and making auditory processing more difficult. Therefore, when the acoustic signal is distorted to a point where it sufficiently challenges the CANS, the resulting difficulty is so pronounced that it can be used as an indicator for the presence of APD, and this fact forms the basis of all behavioural speech tests of central auditory function (Keith, 1994; Mueller & Bright, 1994).

**Frequency content and speech**

The normal speech spectrum encompasses frequencies from below 100 Hz to just above 8000 Hz (Black, 1959; Beasley & Maki, 1976; Rintelmann, 1985; Noordhoek et al., 1999). Filtering of speech eliminates a portion of this frequency spectrum: The signal is passed through a filter that rejects either the high frequencies (low-pass filter) or low frequencies (high-pass filter) or a combination of both (band-pass filter).

The difficulty of the test depends on both the specific frequency at which the filter is applied and the rejection rate of the filter - as both affect the degree with which the speech signal is distorted (Rintelmann, 1985; Bornstein et al., 1994). An example of a low-pass filter with a 1000 Hz cut-off is shown in Figure 1 on page 25.

Removing high frequencies affects consonant recognition more than vowel recognition, while removing low frequencies affects vowel recognition more than consonant recognition. Consonant recognition is more critical to speech understanding than vowel recognition (Rintelmann, 1985; Bornstein et al., 1994; Assmann & Summerfield, 2004), and so the lower the filter, the more demanding the test becomes due to the decreasing amount of high frequency energy (Rintelmann, 1985).
Consequently, provided the components between 250 to 3500 Hz continue to be transmitted, the normal high fidelity bandwidth of speech can be reduced without negatively affecting speech intelligibility (Egan & Weiner, 1946; Beasley & Maki, 1976; Bornstein et al., 1994). Therefore, the low-pass version of the adaptive speech test was chosen as the test of choice in stage three of this study.

Figure 1: A plot of the speech spectrum with a 1000 Hz low-pass filter overlayed. With this filter implemented, all spectral information to the right side of the filter is removed from the stimuli.
Application of filtered speech testing to APD diagnosis in children

Ultimately, researchers began applying various versions of the low-pass filtered words test to children who were showing processing difficulties in the classroom. Over the past three decades, a greater focus has been placed on identification of APD in children, as professionals in the speech, hearing, and education fields recognise a link between school performance and subtle difficulties in the processing of auditory signals (Lerner, 1976; Cruickshank, 1981; Lasky & Katz, 1983; Hurley & Singer, 1985; Katz, 1992).

It is now commonly accepted (Willeford, 1985; Ferre & Wilber, 1986; S. Jerger et al., 1988) that APD is the cause of many cases of classroom learning difficulties. The adaptation of this category of speech tests for use with children began in the 1970s (Farrer & Keith, 1981). Researchers utilised the approaches used in site-of-lesion work with adults, as a model for their studies with children - based on the assumption that the APD abnormality functions in the same way as a CANS lesion (Matkin & Hook, 1983; Bamford & Saunders, 1991).

The various versions of the filtered words test tap auditory perception of degraded speech or speech that is compromised by a poor acoustic environment. Understanding low-pass filtered speech is a type of auditory closure task, i.e., the stimuli is filtered so that the some of the acoustic spectrum is absent and the individual must fill in the missing information in order to comprehend the message.

This category of tests is based on functional auditory abilities that are used in a typical listening situation. Everyday examples of this functional ability include the situation where a person is trying to listen to speech in the presence of background
noise, such as a child in a noisy classroom. Other examples include listening to a person who is:

- Speaking while in a different room to the listener;
- Speaking while they have their back to the listener;
- Speaking in a large room such as a lecture theatre or auditorium;
- Speaking with a foreign accent; or,
- Speaking very rapidly or with poor articulation.

**Commercially available versions of the filtered speech test for children**

Test batteries (Flowers et al., 1970; Willeford, 1977; Keith, 2000c) have been specifically designed to assess the central auditory abilities of children, and filtered speech category of tests have been incorporated as subtests into many of these. However, instead of identifying the presence or absence of a lesion, these tests attempt to assess the functional integrity of the CANS by stressing the auditory mechanisms at each of its various levels to draw out any deficits that may explain the learning handicap (Baran & Musiek, 1999).

Subsequent research (Costello, 1977; Dempsey, 1977; Martin & Clark, 1977; White, 1977; Willeford, 1977; Musiek et al., 1984; Ferre & Wilber, 1986; Singer et al., 1998) has further supported the use of low-pass filtered speech tests in the diagnosis of APD in children. Both Ferre and Wilber (1986), and Singer et al., (1998) found the low-pass filtered speech test to be one of the most sensitive indicators among an APD battery of tests.

However, there is also controversy regarding the parity of test results of children with APD, and adults with CANS lesions (Martin & Clark, 1977; Willeford, 1977; Musiek et al., 1982; S. Jerger et al., 1988). Musiek et al. (1982) determined low-pass filtered speech tests to be the least sensitive among several that were
evaluated in a sample of children with APD. Likewise, a study by Martin & Clark (1977) showed only slight discrimination between the children with APD and without the disorder, and along with Willeford’s (1977) study, produced a wide range of data for both groups. In a comparative study by Jerger and colleagues (1988), performance on degraded monotic speech perception was found to be consistently abnormal for children with confirmed lesions in areas of the brain important for auditory perceptual function, but normal for children with suspected APD.

It seems, therefore, that children classified as having APD may or may not exhibit abnormal scores on monaural, low-pass filtered speech tests. Confusion in the literature has cast doubt over the utility of the filtered speech test in APD diagnosis, and led Rintelmann (1985) to the conclude that monaural, low-pass filtered speech tests, in their present state of development, should be viewed only as a gross screening test for APD.

**Inconsistencies in the research of filtered speech tests**

A review of the literature shows there have been clear inconsistencies between the studies carried out on the sensitivity of low-pass filtered speech tests for determining APD in children. Experimental variation introduced by numerous variables, including the type of speech material used (type of word lists used), subject response method (open-set vs. closed-sets), scoring method (correct or incorrect vs. phonemic analysis), and the acoustic properties of the presented speech (filter characteristics and delivery mechanism) have a marked effect on test scores.

The low-pass filtered speech test that is part of the Flowers-Costello Test of Central Auditory Abilities, became commercially available in 1970 (Lasky & Katz, 1983). The test uses closed-set, fill-in-the blank sentences that have been low-pass filtered to 960 Hz (Flowers et al., 1970). Alternatively, the Ivey Filtered Speech Test
included in the Willeford central test battery, uses open-set Michigan CVC words low-pass filtered with a 500 Hz cut-off and an 18 dB per octave rejection rate (Willeford, 1977). Most recently, the SCAN Filtered Words subtest (Keith, 1986) released in 1986, also uses open-set response, but with a low-pass filter at frequency 1000 Hz, and rejection rate of 32 dB per octave.

Earlier studies tended toward a low-pass filter frequency of 500 Hz. This was based on the assumption that if it was successful for diagnosing cortical lesions in adults, then it would be satisfactory for assessing central auditory abilities in children (Farrer & Keith, 1981). Subsequent research (Willeford, 1977; Farrer & Keith, 1981; Dempsey, 1983) has shown that a low-pass filter frequency of 500 Hz results in a test that is too difficult for children without APD, let alone for children with the disorder. Such a low filter was found to produce poor mean scores with wide variation amongst all groups, making it difficult to distinguish between children with and without APD.

A study by Bornstein et al., (1994) used the North-western No.6 word lists presented at 70 dB HL, with a low-pass filter set at 800 Hz, 1200 Hz, 1500 Hz & 1700 Hz. The study found the low-pass filters produced mean-correct scores ranging from 30% to 88% for normal listening young adults.

Farrer and Keith (1981) used Phonetically Balanced Kindergarten word lists presented at 50 dB HL and low-pass filtered at 500 Hz, 700 Hz, & 1000 Hz. The study found the low-pass filter levels produced mean-correct scores ranging from 58% to 91% for normal listening children aged between 5 years, 8 months and 9 years. The study determined that a low-pass filter of 1000 Hz was the most successful filter at separating children with APD from children without the disorder, while the 500 Hz and 700 Hz low-pass filters generated considerable overlap between the groups.
From the range of data presented, the variable findings emphasise the need to improve filtered speech testing by removing the barriers described above, in an attempt to restore the efficacy of the filtered speech test in APD diagnosis. Most notable in the lack of systematic investigation into low-pass filtered speech tests is the variation in the level at which the low-pass filter has been applied.

**Ceiling and floor effects of fixed level low-pass filtering techniques**

One method of improving this efficacy is to remove the disparity associated with the range of low-pass filters in use. The inconsistency in the level of low-pass filters employed in previous studies (Flowers et al., 1970; Costello, 1977; Dempsey, 1977; Martin & Clark, 1977; Willeford, 1977; Farrer & Keith, 1981; Musiek et al., 1982; Ferre & Wilber, 1986) has been shown to have significant impact on the ability of the low-pass filtered speech test to differentiate between children with APD and children without (Farrer & Keith, 1981).

Much of this impact is due to the ceiling and floor effects that result from using a constant-level method, such as a fixed-level low-pass filter. For example, if the low-pass filter is set too low, then the test may prove too difficult for normal children, as well as those with APD. The test’s low ceiling will make all children appear as though they have APD, as the extent of the disorder is concealed because the dependent measure is not sensitive to values above a certain level (Mitchell & Jolley, 2004). Both groups will achieve poorer scores, and there will be no way of distinguishing between the children with and without APD. On the other hand, a low-pass filter that is set too high will result in a larger number of children achieving higher scores, even though other tests for APD have shown some of these children to have some form of the disorder. The test’s high floor will make children with APD appear normal, as the extent of the disorder is concealed because the dependent
measure places too high a floor on what the lowest response could be (Mitchell & Jolley, 2004).

Therefore, the concern with using a fixed low-pass filter is that the ceiling and floor effects can cause misleading tests result, and ultimately misdiagnosis. A child who performs poorly on a test with a low-pass filter set at 1000 Hz would fail and be suspected of having APD. However, if the low-pass filter had been set at just 100 Hz higher, then the same child may have performed far better, passed the test and been declared normal.

**Adaptive procedures**

One way of avoiding the ceiling and floor effects introduced by constant-level methods is to use an adaptive procedure. An adaptive procedure is a method in which the subsequent presentation of a test item is determined by the subject’s responses to the preceding test items (Levitt, 1971; Leek, 2001; Zera, 2004).

The impetus to use an adaptive procedure rather than the constant-level method currently being used in low-pass filtered speech tests is the simple proposal that a child is measured most effectively when the test tasks are neither too difficult nor too easy. In assessing a child’s ability to understand distorted speech, this level occurs when the child responds correctly to a predetermined percentage (e.g., 50%) of test items administered. Consequently, adaptive testing results in the selection of test items during the testing process that are appropriate in difficulty level for a specific child. Adaptive procedures continue until an established criterion for test termination has been met.
Benefits of adaptive procedures

Previous studies (Levitt & Rabiner, 1967; Levitt, 1971; Bode & Carhart, 1973; Mackie & Dermody, 1986; Zera, 2004) have emphasised the potential advantages of adaptive techniques over constant-level methods. These include the avoidance of ceiling and floor effects from the relative freedom of restrictive assumptions, greater flexibility, swift estimation of test reliability, improved efficiency, high precision and reliability - and all at a significant savings in time over constant-level methods (Leek, 2001).

Ceiling and floor effects are avoided, because there is no restricting limit on the dependent variable, which in this case is the level at which the low-pass filter is fixed (Mitchell & Jolley, 2004). Using an adaptive procedure, the recognition threshold is determined by the ability of the listener. Therefore, unlike the constant-level methods used previously, the test is not governed by the frequency at which the low-pass filter is fixed. Instead of generating a percentage correct score at a specific low-pass filter level, the subject achieves a given percent-correct point on the response curve. This allows specific thresholds to be established without the restriction of assumptions - such as, deciding the fixed level of the low-pass filter. Therefore, adaptive procedures provide more flexibility than constant-level methods, because they allow the investigator to determine the percentage-correct threshold as it corresponds to the point on the rising portion of the performance-intensity curve (Levitt, 1971).

The adaptive procedure is also very efficient (Zera, 2004), as it quickly eliminates measurements taken far from the threshold in question. Greater efficiency generates more accurate results, as the test becomes less susceptible to variables such as attention span, fatigue, and motivation.
Aims

The purpose of this study was to evaluate the hypothesis that a computerised adaptive form of the filtered speech test can serve as a functional tool for distinguishing children with APD from children without the disorder. The present study hoped to find a positive correlation between the required acoustic bandwidth and other accepted measures of auditory processing ability.

As discussed above, a review of the literature has revealed conflicting views on the effectiveness of the low-pass filtered speech test as a tool for the diagnosis of APD. However, inconsistent research methods, and a great deal of variation concerning the appropriate level of the low-pass filter used in such tests are responsible for much of the confusion. Floor and ceiling effects inherent in constant-level procedures, such as fixed level low-pass filtered speech tests, limit the effectiveness of the test in its ability to distinguish between children with and without APD.

The use of an adaptive procedure is an excellent solution to the ceiling and floor effects that have plagued the filtered speech test, as it free of the restrictive assumptions that create such factors.
Hypotheses

The following hypotheses are proposed:

i) An adaptive computerised version of a low-pass filtered words test will produce results that are reliable over repeated administrations of the measure;

ii) An adaptive computerised version of a low-pass filtered words test will have greater efficiency and greater sensitivity in its ability to discriminate between children with and without APD, as there will be a significant difference in the scores on the filtered speech tests between subjects with APD compared to subjects without APD;

iii) Adult participants will perform significantly better on an adaptive computerised version of a low-pass filtered words test than children due to maturational changes of the CANS that provide more efficient auditory processing; and,

iv) There will be a strong correlation between the results of the adaptive computerised version of a low-pass filtered words test and the results of other test of filtered speech designed for APD diagnosis.
Chapter Two

GENERAL METHODS
Method overview:

A software programme (UC MAST) was developed for this project to assess word recognition ability in children and adults. In this procedure, the corner frequency (Hz) at which a word was low-pass filtered on each presentation was determined by performance on previous presentations. Through the analysis of the data produced by this adaptive process, the UC MAST calculated the low-pass corner frequency threshold at which a participant correctly identified either 50% or 70.7% (hereafter, abbreviated to 71% for convenience) of monaural low-redundancy stimuli. The stimulus was delivered acoustically to the participant just prior to four test alternatives being displayed on the monitor. The task for the participant was to choose the visually displayed test item that corresponded to the word presented acoustically.

Chronologically, the study can be divided into three stages. The first stage of the study involved testing the programme using a variety of parameter settings to establish the most efficient and accurate parameter configuration for subsequent testing. Both the UC MAST and the procedure itself were continually enhanced and refined throughout the course of the study.

In the second stage of the study, the final configuration determined in stage one was implemented and preliminary trials were conducted on a sample of adult participants to pilot test the programme. This stage of the study was carried out to determine any potential problems with the UC MAST or test protocol that required addressing prior to conducting the main part of the study.

In the original outline of the project, it was proposed that the third and final stage of the study would involve the testing of child participants with and without APD. As described earlier, the aim of the study was to test both groups of children to determine if there was significant difference between their performances on the UC
MAST as a result of the differences in their auditory processing abilities. However, difficulties were encountered in sourcing children with APD who were available to perform the UC MAST. As a result, the original aim of the study was modified. Consequently, stage three of the study comprised the testing of normal children, as well as an additional sample of adult participants, to determine the effects of maturation on the UC MAST performance.

Additionally, the child participants were tested on the SCAN-C test for auditory processing disorders in children. Their results for this test were compared against their results for the UC MAST to determine whether there was a correlation between the low-pass filter threshold for the participant and the participant’s auditory processing ability, as determined by the SCAN-C test. It was expected that a child’s performance on the Auditory Closure tasks of the Scan-C test would match their performance on the UC MAST.

The remainder of this chapter describes the design of the UC MAST and provides a general description of the UC MAST procedure, common to all stages of the study. Following this chapter, the ensuing three chapters describe the study in its chronological order, with each chapter representing a specific stage of the study as mentioned above. For convenience and simplicity, each of these chapters contains an individual method, results and discussion section pertaining to the particular stage of the study.

**UC MAST design and protocol**

Using National Instruments LabVIEW 8.20, Dr Greg O’Beirne wrote the UC MAST programme. LabVIEW is a graphical development environment for signal acquisition, measurement analysis, and data presentation.
The protocol developed by Mackie and Dermody (1986) was used as a starting point for the project, and was modified through the course of the study. The protocol was a simple up-down adaptive speech threshold procedure in which the level of filtering applied to the stimulus was adjusted by a fixed percentage after each correct or incorrect response. The test was terminated and the threshold was calculated after a set number of changes in direction or “reversals, as discussed in more detail on the following pages.

Depending upon the purpose of the test, either the UC MAST X50 or X71 % threshold was calculated as the average of the midpoints between each reversal, converging on the X50 or X71 point of the psychometric function. This was equivalent to the participant’s 50% or 71% threshold. This was achieved using a transformed up-down method based on the “1 up- 2 down” rule (Levitt, 1971), where the change in stimulus level was dependent on the outcome of two or more of the preceding trials. The level of the stimulus was increased with every incorrect response, and decreased after two successive correct responses.

The efficiency, accuracy and duration of the adaptive tracking procedure was dependent on a number of parameters, including step size, number of reversals and starting LPF value. The following paragraphs provide an explanation of the function for each of these parameters. The rational and significance for setting the values for these parameters is the focus of the following chapter, in which the optimal configuration of these parameters is considered.

**Step size**

Two alternate step sizes – referred to as the “initial increment” and “working increment”, were employed for both the 50% and 71% tasks. The two types of increments are displayed in Figure 2 on page 40. The initial increment was set to a
larger value than the working increment, to quickly provide an approximate estimate of threshold, so that the participant’s true threshold was approached more rapidly. After a set number of reversals, the step size changed from the initial increment to the working increment so that the participant’s threshold was approached more precisely.

**Practice reversals & real reversals**

As mentioned previously, a set number of reversals were required for the UC MAST to reach completion. This number of reversals consisted of both “practice reversals” and “real reversals” as displayed in Figure 2 on page 40. Practice reversals were designed to allow the participant to become familiar with the task and included the initial reversals using the larger initial increment, and the first reversal using the smaller working increment. Consequently, the number of reversals required to change the step size from the initial increment to the working increment was one less than the value set for the number of “practice reversals” via the UC MAST interface. The number of practice reversals was set at two for stages one and two of the study, and increased to five for stage three of the study, for reasons discussed in chapter four.

Real reversals refer to the remaining reversals that involved only the smaller working increment. Using the protocol implemented by Mackie and Dermody (1986) as a guide, the number of real reversals required for statistical significance was set at thirteen for the current study. As mentioned above, the UC MAST threshold was calculated as the average of the midpoints between each reversal. Therefore, to improve the accuracy of the test, the practice reversals were excluded and only the midpoints for the real reversals were included in the calculation of the UC MAST threshold.
Figure 2: An example of the initial and working increments and practice and real reversals incorporated in the UC MAST. The initial increment refers to the larger step size designed to converge rapidly on the area of approximate threshold, while the smaller working increment is designed to approach the threshold with more precision. The practice reversals include all of the reversals using the initial increment and the first reversal using the working increment. The real reversals incorporate the remaining reversals based on the working increment.
For stages one and two of the study, a total of 15 reversals were required for completion of the UC MAST, with the change in step size from the initial increment to the working increment occurring after the first reversal – based on the procedure used by Mackie and Dermody (1986). For stage three of the study, a total of 18 reversals were required to complete the UC MAST, with the change in step size effective after the initial four reversals. This change in procedure was based on the data obtained during the first two stages of the study, as explained in the following chapters.

**Starting LPF frequency**

Another parameter that influenced the duration and the accuracy of the UC MAST was the “starting LPF frequency”. The starting LPF frequency was the initial level at which the low-pass filter was set and consequently, determined the amount of spectral information missing from the first word presented in each test. The effect of the starting LPF frequency is discussed in the following chapter.

All of the above mentioned parameters were adjusted prior to test administration via the UC MAST interface as described later in this chapter.

**Selection of Speech Stimuli**

Speech audiometry has been used in paediatric audiological assessment for many purposes. As a stimulus, speech is useful with infants and young children because it has high interest value and a complex spectrum (Gravel & Hood, 1999). However, speech tests can have a wide variety of properties (Foster & Haggard, 1987), including open versus closed format, vocabulary difficulty, word structure.
The choice of appropriate stimuli for this project was based on the following criteria, as suggested by Jerger and Jerger (1983):

- Word lists were four-alternative, forced-choice closed-response format;
- Word lists were of appropriate vocabulary for young children;
- Word lists were presented in a familiar accent; and,
- Words were monosyllabic in structure.

A forced-choice closed-response word set was chosen based on previous research (Olsen & Matkin, 1979; Meyer & Pisoni, 1999) which suggested open-set formats were too difficult for children with limited vocabulary skills. As the UC MAST was designed to test auditory processing ability and not a child’s vocabulary skills, the closed-response format was implemented. Ross and Lerman (1970) further suggested that if a child has a history of conductive hearing loss then their responses may be unintelligible to the examiner, therefore increasing the risk of administrator bias and error. A forced-choice method such as that implemented in the UC MAST allows the child to select the answer themselves, eliminating any chance of subjective error.

A four-alternative forced-choice word set was chosen as the optimum number of word choices per presentation, as tests involving five or six options can lead to the test being prolonged due to extended scanning and response times (Foster & Haggard, 1987). Less than four word alternatives would have allowed too much chance of randomly guessing the correct answer, increasing the probability from 33% to 50%, for three and two word options respectively.

Word familiarity varies from person to person, but each language contains words that are generally more familiar than others. Therefore, word lists specific to the country of testing were sought, as a listener will correctly identify a greater
number of familiar words than unfamiliar words (Brandy, 2002). This opinion is further supported by Wright (1987), who suggests the words used in any given speech test should be consistent in terms of their structure and roughly homogenous in their intelligibility, i.e., comparable in the average person’s ability to identify them.

Monosyllabic word lists developed for auditory perceptual testing include one-syllable words that are phonetically balanced, i.e., the beginning and ending phonemes are chosen so that they approximate the relative frequency of phoneme occurrence in everyday language (Olsen & Matkin, 1979). In speech tests, studies have shown that monosyllabic words are more effective stimuli for challenging the CANS than spondees (Brandy, 2002).

Consequently, the Australian recording of the word lists from the Northwestern University Children’s Perception of Speech (NU-CHIPS) test (Elliot & Katz, 1979) were chosen as the speech stimuli for the UC MAST and the acoustic recordings of the word lists were taken from the "Speech Recognition Materials" CD 1 produced by the National Acoustic Laboratories (Chatswood, NSW, Australia). The stimulus words from the NU-CHIPS lists were stored as “wav” files on the PC that ran the UC MAST.

In their development of the NU-CHIPS, Elliot and Katz (1979) combined the concept of phonemic balance with monosyllabic words that were documented to be in the recognition vocabulary of normal children older than 2.5 years of age.

The test includes 65 word pictures and interchanges words as test items and foil items. Simple words are represented in a four-alternative picture set, and the child responds by choosing the picture they think corresponds to the presented word (Mackie & Dermody, 1986). As the test was designed in the USA, some of the pictures may have been unfamiliar to New Zealand children. For example, the picture
of an American school is different compared with the image that a New Zealand child may have of a New Zealand school. Consequently, words were used in place of the pictures, as shown in Figure 3 on page 45.

A sound level normalization process was included in the design of the UC MAST, as low-pass filtering causes energy to be removed from the output signal causing a perceived loudness difference between the different stimuli. To partially compensate for the loss of amplitude during the filtering procedure, the peak amplitude of the time-domain waveform of the filtered signal was normalized to the peak amplitude of the original signal. While this was not as accurate as RMS normalisation methods, it was sufficient for this application as it provided adequate loudness when presented at supra-threshold levels.

Presentation level to achieve maximum word recognition scores (WRS) on the NU-CHIPS test is affected by age in normal hearing subjects (Elliot, 1982). As a consequence, the current study used a presentation level of 60 dB HL, a level well above the threshold to ensure that the level at which the stimuli was presented did not have a negative affect on the WRS.

The aim of any filtered words test is to sufficiently tax the CANS so that the combined redundancy of both the auditory system and the acoustic signal are overcome. The filter used in the UC MAST was a 32nd order Butterworth filter, which had a rejection rate or slope of approximately 230 dB per octave. Consequently, the slope of the filter used in the UC MAST was much sharper than those used in other filtered words tests (Flowers et al., 1970; Willeford, 1977; Keith, 1986, 2000c). The aim of implementing such a sharp filter was to make the UC MAST a more difficult test in terms of auditory processing, and therefore a more sensitive measure of auditory processing ability.
Figure 3: A screenshot of the UC MAST test window, showing the four test word alternatives that were used in place of the original NU-CHIPS pictures.
UC MAST test procedure

For stages one and two of the project, testing was conducted in the University of Canterbury Speech and Hearing Clinic (UoCSHC). For stage three of the project, both the UoCSHC and locations outside of the university were used for testing.

Equipment

A schematic representation of the UC MAST set-up is displayed in Figure 4 on page 47. With this set-up, a personal computer (PC) ran the UC MAST programme, controlled the stimulus presentation, sampled the participant’s responses and executed the adaptive procedure.

An audiometer was connected to the PC via a twin RCA to 3.5mm cable and the signal level of the stimuli was set to 60 dB HL. The cable ran from the 3.5mm audio line out socket of the PC and into the left and right channel inputs of the audiometer. The attenuated signal from the audiometer was delivered to the participant via headphones. An external monitor was connected to the PC via the monitor out function and displayed the four test word alternatives visually to the participant.

All testing at the UoCSHC were performed in a double-walled sound-treated chamber with a GSI-61 audiometer (Grason-Stadler Corp., USA) and a Telephonic TDH-39P supra-aural headphone housed in a MX 41/AR cushion.
Figure 4: Schematic representation of the UC MAST set-up configuration, illustrating the required interconnection between each of the components.
Outside of the university, testing was performed in quiet isolated test rooms. The test rooms were not sound treated as they were situated on-site where the subjects could be accessed. The test rooms were chosen on the basis that they were the quietest rooms in the testing location. A NA-24 sound level meter (RION Corp., Japan) was used to monitor the noise floor in the test rooms where ambient noise measurements taken periodically averaged less than 40 dBA. The maximum noise floor recorded during any one administration of the UC MAST was 54 dBA. A stimulus presentation level of 60 dB HL ensured an average signal to noise ratio in excess of the recommended +15 dB HL (Nelson & Soli, 2000).

A CE10 Clinical Hearing Evaluator (Interacoustics Corp, Denmark) and Telephonic TDH-39P supra-aural headphones housed in MX 41/AR cushions were used for testing. For each participant, the examiner (the author) ensured proper headphone placement.

Throughout the project, an Evo N800c laptop PC (Compaq Computer Corp, Korea) was used to run the UC MAST. For stages one and two of the project, each participant was positioned in front of an external monitor that displayed the test alternatives. During these stages of the project, participants used a mouse to make their selection from the four alternatives displayed on the external monitor. In stage three of the project, a Elo ET1715L 17” desktop touch monitor (Tyco Electronics Corp., USA) replaced the external monitor and consequently, the mouse was no longer required as the participant simply used their finger to point and make their selection from the four test alternatives. The touch monitor was positioned at a comfortable viewing height and within reach of the participant for easy selection of the appropriate test item.


Calibration procedure

Prior to administration of the UC MAST, the output signal level of the PC was calibrated to ensure the stimuli were presented at the correct intensity. The calibration of the signal level used the same procedure as for the CD version of the NU-CHIPS test. The calibration track from the CD was stored on the PC as a wav file, and accessed via the “Calibration” menu of the UC MAST.

Pressing the “1kHz tone” button on the UC MAST calibration menu initiated the calibration track, as shown in Figure 5 on page 50. The input gain of the audiometer was then adjusted for both left and right channels until the respective VU meters of the audiometer read zero.

The intensity output of the stimuli was set at 60 dB HL for both channels via the audiometer attenuators. The “level” (dB) slider of the UC MAST calibration menu was adjusted to 60 dB HL to match the intensity output of the audiometer.

General UC MAST procedure

Prior to their first administration of the UC MAST, each participant was required to be free of known motor skill problems and pass a pure-tone air-conduction screening test at 15 dB HL at octave intervals of 500 Hz through 4000 Hz. No attempt was made to control for gender throughout this study, as previous studies (Keith, 1986; Amos & Humes, 1998; Keith, 2000c) suggest similar outcomes for males and females on tests of auditory processing.

The participants were seated facing a monitor positioned at a comfortable height for viewing the test items. Each participant was provided with the same set of instructions (listed in Appendix I) to reduce any tester bias. The participants’ first name, surname, date of birth and pure tone average (dB) were entered into the provided spaces of the “Client details” menu displayed in Figure 6 on page 50.
Figure 5: A screenshot of the UC MAST calibration window. Pressing the “1kHz tone” button [A] initiated the calibration track of the UC MAST. The “level” (dB) slider [B] of the UC MAST programme was adjusted to the match the intensity (dB HL) output of the audiometer.

Figure 6: A screen shot of the UC MAST “client details” window. The participant’s first name, surname, date of birth and pure tone average (dB) were entered into the spaces provided [A]. The stimuli mode of delivery was selected by toggling the button until the right, left or binaural option was displayed [B]. The low-pass filter UC MAST option was selected [C] and the start button was selected to begin the test [D].
This information was saved and later reproduced in the file that was generated at the completion of the test. The low-pass filter mode of the UC MAST was chosen, and the headphones were placed on the participant’s head.

The delivery mode for the stimuli was selected by toggling through the left, right and binaural modes of the UC MAST. For the remainder of this study, a notation consisting of a letter and number are used to denote the delivery mode of the stimuli and the number of the attempt for the participant at the UC MAST. For example, a notation of “B1-50, R2-71, L3-71, L4-50, and R5-50” corresponds to a binaural 50% administration for the participant’s first UC MAST attempt, a right ear 71% administration for the second attempt, a left ear 71% administration for the third attempt, and left and a right ear 50% administration respectively for the fourth and fifth attempt. When the participant was ready to commence the UC MAST, the “Start” button was selected to begin the test.

**Default UC MAST settings**

Prior to each administration of the UC MAST, programme parameters were set to values that would most likely minimise the learning effect inherent in repeated measures (e.g., random presentation of all 200 words) and reduce the possible threat to internal validity posed by variations in test procedures and instrumentation. As the NU-CHIPS word lists were used as a source of test items, each of the four word lists (Book A List 1 & 2, Book B List 1 & 2) could be selected individually or combined to provide a pool of 200 test items for a particular trial of the UC MAST. The combined pool of 200 test items was chosen as the option for all trials of the UC MAST performed in this study, as it reduced a participant’s chance of repeated exposure to the same test item during subsequent trials of the UC MAST.
To further decrease the repetitiveness of each individual trial of the UC MAST, and therefore minimise the practice effect, the presentation order and the screen position for each set of test items were randomised. As discussed in chapter five, the “Delay” value was increased from 500 to 1000 for stage three of the project, while the remaining parameter values for the “Other set-up” menu were kept at their default settings. The settings for the above parameters were made via the UC MAST “Other Set-up” menu, as displayed in Figure 7 on page 53.

The values for the starting LPF, the number of practice reversals, and the size of the initial and working increments were adjusted through UC MAST interface prior to administration of the test, as shown in Figure 8 on page 53. The values for these parameters were based on the final parameter configuration as determined during the first stage of the project, and updated based on the findings from stage two of the study.

This project was reviewed and approved by the University of Canterbury Human Ethics Committee (Appendix I).
Figure 7: A screen shot of the UC MAST “Other Set-up” menu showing how to select the source of the test items [A] and how to randomise their screen position [B] and presentation order [C]. The delay value controlled the length of time between selection of a test item and the following stimuli presentation [D].

Figure 8: A screen shot of the UC MAST “Filtering Set-up” menu. The values for the starting LPF [A], the step size of the initial and working increments [B], and the number of practice reversals [C] were entered prior to administration of the UC MAST.
Chapter Three

FINAL PARAMETER CONFIGURATION
Method

High efficiency was a desired attribute for the UC MAST. A series of trials of the 71% UC MAST were conducted to determine the programme parameter values that produced the most accurate determination of threshold using the lowest number of stimuli presentation. The following three parameters and their listed values were systematically varied, as these were the characteristics that had the largest influence on the efficiency and accuracy of the result:

- Starting LPF (Hz): 500, 1000, 1500;
- Initial increment (%): 15, 12.5, 10; and,
- Working increment (%): 5 and 2.5.

The UC MAST test procedure was followed as described in the general methods section. For consistency and efficiency, only the right ear was tested during this stage of the study. For each configuration, the value for two of the parameters were kept constant and the remaining parameter was modified to determine the combination of values that yielded the most efficient configuration for the UC MAST. A single participant (the author) completed three separate trials for each of the 18 possible configuration sets following a test order of R1-71, R2-71, and R3-71. Each trial for a specific configuration was performed on a separate day over three consecutive days. Six additional trials were performed using the final parameter configuration to determine whether the threshold tracking procedure was consistent over an extended number of trials.
Results

For each of the configurations tested, the mean 71% UC MAST threshold and the standard deviation for each set of three trials were calculated. Additionally, the mean number of presentations required for the test to reach completion was also calculated. The results were tabulated and are displayed in the order in which the configurations were tested in Table 1 on page 57.

These results indicated that configuration number ten (bolded in Table 1) consisting of a starting LPF value of 1000Hz, an initial increment of 12.5%, and a working increment of 5%, was one of the more efficient configurations for the UC MAST. With this configuration, the test required a mean of 44 presentations (±1 presentation) to reach a 71% UC MAST threshold of 401 Hz (±4 Hz).

This configuration was chosen as the final configuration as it produced the lowest standard deviation for the 71% UC MAST threshold from its three trials, suggesting that this configuration was the most reproducible of all the configurations tested. Additionally, with this configuration the 71% UC MAST reached test completion using the fourth lowest number of presentations of all the configurations tested. This result suggests that apart from being the most precise configuration, it was also one of the more efficient configurations. Configuration numbers one, four, and five were more efficient than configuration ten, as they reached test completion in fewer mean presentations, however these configurations produced thresholds with much larger standard deviations than configuration ten, suggesting that they were less precise.
Table 1: Individual trial and summary results for the UC MAST parameter configurations that were trialled in stage one of this study. Three separate trials were performed for each set of configurations and the resulting 71% thresholds and the number of presentations required to complete each trial were recorded. The mean and standard deviation were calculated for the 71% UC MAST thresholds, as well as for the number of trials required for test completion.

<table>
<thead>
<tr>
<th>#</th>
<th>Starting LPF (Hz)</th>
<th>Increment (%)</th>
<th>71% UC MAST LPF threshold (Hz) per trial</th>
<th>Number of presentations per trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Working</td>
<td>Trial 1</td>
<td>Trial 2</td>
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<td>1</td>
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<td>352</td>
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<td>436</td>
<td>661</td>
</tr>
<tr>
<td>18</td>
<td>1500</td>
<td></td>
<td>641</td>
<td>432</td>
</tr>
</tbody>
</table>
Once the final threshold configuration was established, additional trials were conducted to determine whether the threshold tracking procedure was consistent over many trials using the final parameter configuration. The threshold tracking procedures of the nine trials performed using the final configuration is displayed in Figure 9 on page 59. The mean 71% UC MAST threshold for the nine trials was 456 Hz (±53 Hz) and the mean number of presentations required for test completion was 49 (±5).

As shown in Figure 9 over the page, the threshold tracking performance using the final parameter configuration remained consistent over the repeated trials, and the mean number of presentations required to reach threshold remained below fifty presentations.

Displayed in Figure 10 on page 60 are the adaptive tracking data recorded using a starting LPF value of 1500 Hz and a working increment of 2.5%. These results indicates that if the starting LPF value was set too high or the working increment was set too low, then the UC MAST took much longer to complete and produced results which may not have been valid indication of the participant’s true threshold. The effect of different parameter values is discussed in the following section.
Figure 9: 71% UC MAST threshold tracking data for nine separate trials of the UC MAST using the final parameter configuration that included a starting LPF of 1000Hz, and an initial and working increment of 12.5%, and 5% respectively. Each of the horizontal lines represents the 71% UC MAST threshold for a specific trial using the final parameter configuration. The tracking data for each trial shows how the adaptive procedure tracks the participant’s threshold in larger initial increments and then in smaller working increments.
71% UC MAST threshold tracking data using a 1500Hz starting LPF, 10% initial increment, and a 2.5% working increment

Figure 10: 71% UC MAST threshold tracking data for three separate trials using a configuration that included a starting LPF of 1500Hz, and an initial and working increment of 10%, and 2.5% respectively. The high starting LPF and small working increment prolonged the tracking procedure and the UC MAST reached completion before the true threshold was recorded.
Discussion

In a clinical setting, time is paramount and an efficient test saves the clinician valuable time that is better utilized in other areas of the consultation, such as counselling and management of the patient. A shorter testing time also improves the validity of the result by reducing the effects associated with a patient’s waning motivation, especially in children who are known to have shorter attention spans than adults (Sigelman & Rider, 2005).

The trade-off for high efficiency can be a loss of accuracy. The challenge for the adaptive procedure of the UC MAST was to produce appropriate observations on the psychometric function using maximum efficiency while maintaining a minimum sacrifice of accuracy (Leek, 2001). The aim of this stage of the study was to reduce the number of measurements taken further from the threshold in question while increasing the number of measurements taken closer to the area of approximate threshold.

A balance of efficiency and accuracy was achieved through the manipulation of programme parameters that controlled the adaptive procedure of the UC MAST, specifically the initial starting LPF frequency value and the size of the initial and working increments.

Selection of the starting LPF frequency value

In determining the starting LPF frequency value, three choices (1500 Hz, 1000 Hz, and 500 Hz) were considered. These three choices were based around the filter values employed in previous filtered words tests that used constant level methods, as discussed in the chapter one (Bocca et al., 1954; Flowers et al., 1970; Bornstein et al., 1994). While Hughson and Westlake (1944) emphasized the importance of stimuli
levels beginning below a participant’s threshold, research beginning with Cahart and Jerger (1959) and supported by Green (1989) and Garcia-Perez (1998) was contrary to this original opinion. A starting stimulus level well above threshold is favoured as it provides the participant with a clear understanding of what constitutes the stimulus and avoids confusion in the mind of the participant from the onset.

Conversely, it was important not to begin the UC MAST at a level too far from the threshold region as this reduced the efficiency of the test. As shown in Figure 10 on page 60, a higher starting LPF value of 1500 Hz caused the tracking procedure to begin at such a large distance from the area approximating threshold that the test reached completion before the adaptive procedure had time to determine the true threshold.

For the above reasons (and as a result of the trials conducted during this stage of the study), an initial starting LPF of 1000 Hz was chosen from the three choices tested. As shown in Figure 9 on page 59, the steady decrease of the threshold tracking data for this starting LPF towards a lower corner frequency indicates that the initial low-pass filter setting provided adequate spectral information to produce a number of clear examples of the stimulus for the participant at the beginning of the session. In all but one of the nine trials, the participant correctly identified the stimuli during the initial test phase allowing the larger initial increment to efficiently reduce the low-pass filter until the area approximating the participant’s threshold was reached.

**Selection of the initial increment value**

The size of the initial increment determined how quickly the low-pass filter was increased or decreased in the preliminary stages of the UC MAST. The effect of the initial increment was dependent on the starting LPF. A higher value for the starting LPF produced words that were easier to discriminate and a participant was
more likely to choose the correct alternative. In this case, a larger initial increment was more beneficial as it allowed the tracking procedure to approach the region of threshold more efficiently, whereas a smaller initial increment wasted too much time presenting stimuli that were easily distinguishable. However, when the participant produced an accidental error during the early phase of the test, a higher initial increment caused the already high starting LPF to shift the tracking procedure an even greater distance away from the threshold region, whereas a smaller value produced a shift in the same direction, but to a lesser extent.

Alternatively, when the starting LPF value was too low for the participant, then they were more likely to choose an incorrect alternative. A higher initial increment produced a subsequent stimulus that was more easily perceived by the participant than a smaller initial increment and wasted less time presenting consecutive stimuli that were below threshold.

Three initial increment values were trialled during this stage of the study – 10%, 12.5%, and 15%. Of the three values, 12.5% was found to be the most suitable initial increment. In combination with a starting LPF of 1000 Hz, the 12.5% initial increment allowed an efficient approach to the approximate threshold region, as shown in Figure 9 on page 59.

At the approximate threshold region, the stimuli became more difficult to discriminate and the size of the increment changed from the initial increment to the smaller working increment following the initial error and allowed the participant’s threshold to be approached more precisely.
Selection of the working increment value

The size of the working increment chosen for the UC MAST was a trade-off between the time taken to reach threshold and the precision of the threshold estimate. A larger working increment would reach the area approximating threshold in fewer steps than a smaller working increment, however the distance between each reversal is also greater - producing a more approximate threshold that is less precise than that determined by a smaller working increment.

According to Levitt (1971), the size of the working increment should be small enough to produce accurate observations relative to the X71 but not so small that the procedure is inefficient. This view is further supported in the literature (King-Smith et al., 1994; Garcia-Perez, 1998), who advised against the use of small steps as they prevent a staircase method from reaching the threshold region prior to test termination.

The 2.5% working increment trialled in this stage of the study provided an example of an increment that was too small in step size, as shown in Figure 10 on page 60. The 2.5% step size wasted too many presentations converging on the threshold and as a result, the test was prolonged and the real threshold was never reached. This problem was more evident when a higher starting LPF was employed, especially if an error was made in the early phase of testing.

The 5% working increment was found to be the most efficient step size for three reasons. Firstly, the magnitude of the change was large enough to quickly converge on the threshold, while still small enough in size to do so without sacrificing accuracy. Additionally, the 5% increment caused reversals to occur more efficiently than the 2.5% increment. The larger percentage change in the amount of spectral information being filtered produced a more perceivable contrast between successive
presentations. Consequently, it was more likely that each reversal was interpreted as above or below threshold and the latter stages of the staircase successfully bracketed the participant’s true threshold. Finally, if the participant produced a sequence of lucky guesses that caused the tracking procedure to sink well below threshold level, the larger increment size would result in the staircase making a quicker come-back to the region of approximate threshold (Laming & Marsh, 1988; King-Smith et al., 1994).

To summarise, the final parameter configuration for the UC MAST was a starting LPF value of 1000 Hz, an initial increment of 12.5%, and a working increment of 5%. This parameter configuration was implemented into the pilot study for the UC MAST, which represents stage two of the project and is presented in the following chapter.
Chapter Four

UC MAST PILOT STUDY
Method

For this stage of the study, a sample of adult participants were chosen to pilot test the UC MAST using the final parameter configuration determined in the previous stage. This stage of the study provided an opportunity to trial the measure to identify any problems with the measure prior to conducting the main part of the study.

Additionally, the randomised order in which data was obtained during this stage of the study provided an opportunity to perform a within-subjects analysis to determine if an ear advantage existed for the UC MAST. Testing the right ear first for half of the participants on each trial, and the left ear first for the remaining participants negated the influence of the learning effect and allowed a true indication of any ear advantage.

Participants:

Ten adult participants with an age range of 18.1 years to 37.4 years and a mean age of 27.4 years (±6.8 years) participated in the second stage of the study. The ratio of males to females was 0.4:1. The adult participants were recruited from the staff and faculty of the Department of Communication Disorders at the University of Canterbury. Participants were approached and invited to participate in the study.

UC MAST test procedure:

Each participant performed the 71% UC MAST under identical conditions on two separate occasions. The time interval between each test session ranged from seven days to ten days. During each session, the left and right ears of each participant were tested individually. For each participant, the same ear was tested first on each occasion. Consequently, the test order was R1-71, L2-71, R3-71, L4-71 for half of the participants, and L1-71, R2-71, L3-71, R4-71 for the remaining participants.
Results

Summary of Results

The overall results for this stage of the study suggested the UC MAST was susceptible to a learning effect with repeated administrations of the test over short time intervals. The influence of the learning effect was reduced as the time interval between administrations of the measure was increased. No significant ear advantage was determined for the group of adult participants during this stage of the study. Correlation between the right and left ears for each participant was poor, probably due the influence of the learning effect.

Results of the first 71% UC MAST test session: Trials one and two

The performance of the participants on the 71% UC MAST was analysed across four trials of the measure. During each test session, the left and right ears of each participant were tested separately. For half of the participants, the right ear was tested first at the beginning of each test session. The remaining participants had their left ear tested first. The individual results for each participant are listed in Table II-1 in Appendix II. The mean threshold scores recorded by all participants for each trial were compared according to test order and irrespective of the ear tested.

Figure 11 on page 69 shows the mean 71% UC MAST corner frequency threshold for each trial. The graph illustrates two important features of the data. First, the mean threshold improved with repeated administration of the test during each test session, with an overall improvement from the first trial to the last trial.
Figure 11: Comparison of the mean 71% UC MAST thresholds obtained by each adult participant during the UC MAST pilot study across four repeated trials in order of test administration. Trials #1 and #3 represent the right ear and Trials #2 and #4 represent the left ear of 50% of the participants. For the remaining 50% of participants, Trials #1 and #3 represent their left ear and Trials #2 and #4 represent the right ear. Brackets represent one standard deviation above and below the mean threshold.
Second, the brackets on the graph that represent one standard deviation (SD) above and below the mean thresholds show that inter-subject variability also decreased with repeated administration of the test during each test session, and over the course of the four trials.

The mean 71% UC MAST threshold for the first trial of the pilot study was 880 Hz (±208 Hz), ranging from 525 Hz to 1152 Hz. The second trial of the pilot study was administered to the participant’s opposite ear following completion of the first trial, and yielded a mean 71% UC MAST threshold of 717 Hz (±130 Hz), ranging from 528 Hz to 930 Hz. The participants performed significantly\(^2\) better on the second trial of the 71% UC MAST in comparison to the first trial by a mean absolute difference of 163 Hz (±182 Hz). As the test order for the right and left ears was randomised, any ear advantage was negated. This significant improvement in test performance suggests the probable presence of a learning effect with repeated administrations of the UC MAST rather than the presence of a specific ear advantage.

**Results of the second 71% UC MAST test session: Trials three and four**

The third and fourth trials were conducted in a separate session, between seven and ten days after the first. The third trial of the 71% UC MAST produced a mean 71% UC MAST threshold of 825 Hz (±181 Hz), ranging from 617 Hz to 1139 Hz. As with the second trial, this result represented a significant\(^3\) decrease in the mean 71% UC MAST threshold score obtained by the adult participants compared with the first trial.

\(^2\) Dependent \(t\) test \([t(9) = 2.8, p = 0.02]\).

\(^3\) Wilcoxin Signed Rank Test \([W=13, T^+=34, T^-=21, P = 0.56]\)
In contrast, performance on the third trial produced a mean increase in the mean 71% UC MAST threshold of 108 Hz (±153 Hz) in comparison to the second trial, however the decline in test performance was not significant\(^4\). The result for the third trial suggests that the probable practice effect that was evident over the first two trials of the UC MAST may have diminished as a result of the longer test interval between the second and third UC MAST administrations.

The final administration of the UC MAST generated the lowest mean 71% threshold of the four trials conducted during this pilot study. The fourth trial yielded a mean 71% threshold of 675 Hz (±109 Hz), ranging from 487 Hz to 822 Hz. The participants performed significantly\(^5\) better on the fourth trial compared with their performance on the third trial by a mean absolute difference of 150 Hz (±142 Hz).

As with the first and second 71% UC MAST trials, the third and fourth trials of the second test session were also performed consecutively. Therefore, the participant showed a significant improvement on the 71% UC MAST on the second trial in each test session (trial two and trial four) compared with the initial trial of the same test session (trial one and trial three respectively).

However there was no significant\(^6\) improvement in test performance when the latter two trials of each test session were compared against each other (trial two and trial four), with a mean absolute difference of 42 Hz (±131 Hz) between the trials.

This result suggests that participants improve their threshold significantly after an initial administration of the UC MAST on each occasion, but no further significant

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\(^4\) Dependent \(t\) test \([t(9) = -2.2, p = 0.05]\).

\(^5\) Dependent \(t\) test \([t(9) = 3.3, p = 0.009]\).

\(^6\) Dependent \(t\) test \([t(9) = 1.0, p = 0.3]\).
improvement occurs when the subsequent administrations of the UC MAST are compared with each other.

Overall, the participants showed a significant\(^7\) improvement in test performance from the first administration to the last administration of the UC MAST by a mean absolute difference of 205 Hz (±180 Hz).

**Comparison of right and left ear results for the 71% UC MAST**

A comparison of the mean 71% UC MAST thresholds of the right and left ears were performed to determine if a significant ear advantage was evident on the UC MAST. The mean UC MAST 71% thresholds for the right and left ears of all participants in this part of the study are depicted graphically in Figure 12 on page 73.

Testing the right ear first for half of the participants on each trial, and the left ear first for the remaining participants negated the influence of the learning effect. The mean 71% UC MAST threshold for the right ear was 778 Hz (±165 Hz), ranging from 573 Hz to 1145 Hz. The mean 71% UC MAST threshold for the left ear was 770 Hz (±160 Hz), ranging from 559 Hz to 998 Hz. The absolute mean difference between the ears of 8 Hz (±226 Hz) was not statistically significant\(^8\), indicating the absence of an ear advantage on the UC MAST.

As shown in Figure 12 on page 73, no significant relationship was found between the right ear and left ear thresholds of each participant during the UC MAST pilot study. For each participant, the same ear was tested at the beginning of each test session. Therefore, this poor correlation is not surprising as a probable learning effect produced improved results for the second ear tested during each test session.

\(^7\) Dependent \(t\) test \([t(9) = 3.6, p = 0.006]\).

\(^8\) Dependent \(t\) test \([t(19) = 0.164, p=0.871]\).
Figure 12: The top figure shows a comparison of the mean 71% thresholds between the right and left ears which was performed to determine if a significant ear advantage was evident on the UC MAST. Testing the right ear first for half of the participants on each trial, and the left ear first for the remaining participants negated the practice effect. No significant difference was found between the right and left ears on any of the trials. The bottom figure is a comparison of the mean right and left 71% UC MAST thresholds (Hz) for all participants during the UC MAST pilot study.
**Analysis of threshold seeking traces**

Analysis of the individual results for each participant highlighted a problem with the default number of practice reversals used during the pilot study. For this stage of the study, the number of practice reversals was set at one. As a result, the working increment took over from the initial increment as soon as the first reversal was detected, causing the tracking system to produce smaller step sizes.

As shown in Figure 13 on page 75, any error produced in the initial phase of the UC MAST caused the larger initial increment to create a shift the threshold tracking system away from the true threshold area, rather than towards the target. As this first reversal produced the change from the larger initial increment to the smaller working increment, an early error caused the shift in direction back towards the threshold area to be prolonged.

In the tracking data examples shown in Figure 13 on page 75, the required number of real reversals was reached and the test was terminated before the true threshold region was bracketed by the staircase procedure. As the threshold is calculated as an average of the midpoints between the working reversals, an early error compromised the accuracy of the test. This problem was addressed by increasing the number of practice reversals for the subsequent administrations of the UC MAST, as discussed in the following section.
Figure 13: 71% UC MAST threshold tracking data for the three participants recorded during the UC MAST pilot study. Threshold tracking data is shown for three participants on the 71% UC MAST recorded during the UC MAST pilot study. An error produced in the initial phase of the UC MAST caused the measure to spend an excess of time recording values away from the threshold region. In the above examples, the required number of real reversals was reached and the test was terminated before the threshold could be determined accurately.
Discussion

The purpose of the UC MAST pilot study was to identify any issues with the measure that required addressing prior to the commencement of the main part of the study. The results obtained during this stage of the project showed that the improvement in the low-pass filter threshold with repeated testing was significant and suggested the UC MAST was susceptible to a learning effect when the measure was administered repeatedly in a short space of time.

Test-retest reliability

In terms of the clinical efficacy, a test must be reliable so that we can be confident that the results obtained from a single administration of the measure are indicative of a patient’s true threshold. Reliability refers to the degree to which the results of a test are repeatable over various administrations at different points in time. Reliability is measured by obtaining several test scores for the same participant. Poor reliability compromises test sensitivity as it makes it difficult to determine whether an individual’s ability is within the normal range (Mackersie et al., 2001; Waegener & Brand, 2005). For the UC MAST test to be considered as a potential clinical tool for the assessment of APD in children, the test must be reliable: producing stable and consistent scores that are indicative of a person’s auditory closure ability.

To minimise random variation in measurement error, the current study aimed for a high level of standardization. The participants were provided with the same word lists, at the same speech level and in the same acoustic environment. Further, all aspects of the equipment were kept consistent, including calibration and the type of transducers used. These precautions to minimise random variation are in good accordance with those suggested by Bamford and Wilson (1979). However, it is
impossible to keep everything constant and factors that may have introduced random error were the time of the day of test administration, the temperature in the room and outside noise.

In an effort to reduce bias, all participants were provided with the same set of instructions and none of the participants were provided with any form of encouragement during the test, as suggested by Bamford and Wilson (1979) and Keith (2000c).

As discussed in the introduction, administrator bias was removed from the scoring of the test through the use of a four-alternative forced choice method. Each response was recorded automatically via the computer running the UC MAST. This prevented the administrator from marking any responses as correct when in fact they were incorrect, or vice versa. However, the chance remained that the subject themselves could accidentally click on a response they didn’t mean to when intending to click on a different word choice. The software automatically calculated the participant’s threshold, removing any chance of mathematical error by the administrator.

Test-retest reliability of the UC MAST was calculated using a paired t-test using the “initial” test data and the “retest” data to determine if there was a significant difference between the two administrations. The determination of a practice effect between the first and second trials of each test session suggests that we cannot be confident the results obtained from a single test of threshold are indicative of the subject’s “true threshold”.

Previous studies that have determined the test-retest reliability of speech intelligibility tests have found similar learning effects (Korsan-Bengtsen, 1973; Rintelmann, 1985; Amos & Humes, 1998; Marriage et al., 2001; Hernwig & Olsen,
Waegener et al (2005) analysed the learning effect on the DANTALE II sentences. As with the current study, a significant learning effect was determined between the first and last test administration. In their review of the SCAN-C test for auditory processing, Amos and Humes (1998) found a significant improvement in the performance of children with a repeated administration of the Filtered Words subtest.

In an effort to diminish the learning effect, Waegener et al (2005) included a practice session prior to the administration of the actual DANTELE II sentence test and found that the learning effect was reduced substantially. The author suggested that the training effect was due to familiarisation with the measurement procedure and the word material. Like the UC MAST, the DANTALE II uses closed-set stimuli. Hernwig and Olsen (2005) suggested that in speech intelligibility tests where word stimuli are limited, learning to recognise the test stimuli is a fairly easy task. Consequently, the remaining learning effect may come from the learning the procedure. This may explain why the learning effect was reduced substantially after the initial administrations of the UC MAST during each test session, and indicates the need for a practice session to be implemented for the next stage of testing. Consequently, in an attempt to reduce this effect, a binaural 50% UC MAST practice run of the UC MAST was incorporated into the method for stage three of the study and a test-rest time interval of seven days was maintained, as discussed in the following chapter.

The decrease in test performance between the second and third trials suggested that the time interval of seven and ten days between subsequent administrations of the UC MAST diminished the practice effect. As suggested by Bamford and Wilson (1979) and McNemar (1969), the test-retest time interval should not be so short that
the participant remembers the test material on the subsequent administration. In contrast, the time period between testing sessions should not be so long that it permits a change in performance due to maturation.

**Determination of ear advantage**

As the test order for stage two of the study was randomised, an additional result of interest was the presence or absence of an ear advantage on the UC MAST. As the CANS attains maturation, the fibres of the corpus callosum extend well into the cerebral hemispheres and are responsible for the interhemispheric transfer of information (Bellis, 2003). As expected and consistent with the findings in the literature (Keith, 2000c; Bellis, 2003), no significant ear advantage was found on the UC MAST for the adult participants.

**Modifications to the UC MAST**

An error in the early phase of a test run - such as lapse in concentration or an accidental word choice caused the threshold procedure to track a long way from the true threshold region, as demonstrated by the three participants in Figure 13 on page 75.

By increasing the number of practice reversals, the duration of the test was prolonged as the overall number of reversals required for test completion was also increased. However, by increasing the number of practice reversals, the threshold tracking procedure became more reliable. Practice reversals were designed to keep the tracking process within the vicinity of the threshold area by reducing the impact produced by an accidental error at the beginning of the test.

As the starting LPF value was set to be above a participant’s threshold, a participant was more likely to score more correct responses than incorrect responses during the early phases of the test. As a result, the larger initial increment allowed the
adaptive tracking process to more quickly converge on the target threshold. If an accidental error was made at the beginning of the test, the next response was likely to be correct as the stimuli was above the threshold level. Once the region approximating the participant’s threshold was reached, any remaining practice reversals would be quickly exhausted as the task alternated above and below threshold level with each consecutive presentation.

Another parameter that required adjusting was the length of the delay from the time a participant chose the target word to the subsequent acoustic presentation of the next stimuli. The default setting for this was 500 ms, however this was increased to 1000 ms after it was found that some adult participants were accidentally making multiple presentations in a row if they held their finger on the mouse button for too long when making their initial selection. As a consequence, the next word would be presented and selected before the subject had a chance to hear the word and make their selection.
Chapter Five

COMPARISON OF ADULT AND CHILD PERFORMANCE ON THE UC MAST
Method

Method overview

As mentioned previously, the aims for this stage of the study were:

- To determine if there was a significant difference in the UC MAST threshold scores between children with normal auditory processing and children with APD;
- To determine if there was a significant difference in the UC MAST threshold scores between children and adults with normal auditory processing; and,
- To determine if there was a correlation between a child’s UC MAST threshold score and their score on the SCAN-C test for auditory processing disorder.

To achieve these aims, three groups of participants were required:

i) Children with APD;

ii) Children with normal auditory processing; and,

iii) Adults with normal auditory processing.

The first and second aims were to be achieved by administering the UC MAST to each of the participants in the above groups. Statistical analysis of their results could then be conducted to determine if there were any significant differences in test performance between the three groups. Unfortunately, difficulty in sourcing children with APD prevented the first aim from being achieved, as discussed in the following section.

To achieve the third aim of the study, each child participant was administered the SCAN-C test for auditory processing disorders. The scores obtained by the children on both the UC MAST and SCAN-C test were compared to determine if
there was a correlation between the two types of filtered words tests. A more detailed explanation of the test procedure is provided below.

**Participant Recruitment**

**Children with APD**

Three different methods for recruiting children with APD were employed during this stage of the study. First, children previously diagnosed with APD were sought via the Group Special Education division of the Ministry of Education. Two sources from within the division – the Advisors on Deaf Children (AODC) and the Lead Practitioner: Speech and Language Therapist (SLT) were contacted and provided with project information sheets outlining the proposed study (Appendix I). The AODC distributed the project information sheets directly to the parents and guardians of children in their care who had previously been diagnosed with APD. The Lead Practitioner passed the information sheets onto fellow SLTs who in turn, distributed them to the parents and guardians of children who had previously been diagnosed with APD.

Five children with a previously diagnosed APD were identified through this enquiry and invited to take part in the study. Unfortunately, three of the potential candidates who accepted the offer could not take part in the study as they were affected by co-existing disorders that impacted their ability to successfully complete the test e.g., motor skill problems. The parents or guardians of the remaining candidates who were suitable for the project either declined the offer or did not provide written consent for their child to take part in the study.

The Audiology Department of Christchurch Hospital provided the second source of potential candidates. At the time of the current study, APD testing was no longer available at the hospital and so children referred for APD testing were placed
on a waiting list. Twenty-six letters were sent to the parents or guardians of these children offering them the option of having the appropriate testing carried out at the UoCSHC. Any child who was subsequently diagnosed with APD was invited to take part in the current study.

Six children accepted the offer and appointments were made at the UoCSHC, where a full APD assessment was performed. These children were assessed using a traditional APD test battery consisting of the child’s version of the Pitch Pattern Sequence Test (PPS); (Pinheiro, 1977), the Dichotic Digits Test; (Musiek, 1983), the Random Gap Detection Test (RGDT); (Keith, 2000b), and a Speech-In-Noise Test consisting of the CVC Word Lists delivered acoustically at a signal-to-noise ratio of 0 dB HL. None of the children who underwent APD assessment were diagnosed with APD. Consequently, all six children were included in the study as part of the “children with normal auditory processing” group.

The third source of potential APD participants was children from St. Teresa’s School in Riccarton, a suburb of Christchurch, New Zealand. St. Teresa’s school is a Decile 6 school. A school's decile indicates the extent to which it draws its students from low socio-economic communities. Decile 1 schools are the 10% of schools with the highest proportion of students from low socio-economic communities, whereas Decile 10 schools are the 10% of schools with the lowest proportion of these students.

Forty-six children aged between eight and twelve years of age were screened for APD through the use of a structured enquiry. Firstly, a letter (Appendix I) was sent to the principal of the primary school. The letter outlined the study, and sought permission to distribute an information pack (Appendix I) and a consent form (Appendix I) concerning the study to the parents or guardians of all the children at the
school who were of the appropriate age. Consent was provided for twenty-six children
to partake in the study.

The letter to the principal also sought permission to distribute a questionnaire
(Appendix I) to each of the teachers at the school who taught the appropriate years
(years 4 to 6). The questionnaire was in two parts. The first part (Part A) aimed to
help the teacher identify if there were any children in their class who showed
symptoms of auditory processing difficulty. The second part (Part B) of the
questionnaire was the Children’s Auditory Processing Performance Scale, known as
the CHAPPS (Smoski, 1990). This questionnaire was a more in depth evaluation that
was to be filled out for each child that had been identified in Part A.

The CHAPPS questionnaire checklist is commonly used by educators and
parents to assess listening difficulties in children (Garstecki et al., 1990). Six listening
conditions were assessed in the 36-item checklist, including noise, quiet, ideal,
multiple inputs, auditory memory/sequencing and auditory attention span. The
CHAPPS assessment was performed by comparing the children identified in Part A to
a reference population of other children of similar age and background. Items were
rated on a scale from +1 (less difficulty) to -5 (cannot function at all).

The teachers at St. Teresa’s School completed CHAPPS questionnaires for
eleven children, of which six children were determined to be “at risk” of having APD
(a raw score of -12 to -130). Parental consent forms were obtained for two of the six
“at risk” children, who subsequently underwent a full APD assessment at the
UoCSHC. Both of these children passed the APD assessment and consequently, were
regarded as having normal auditory processing ability.

Additionally, each of the twenty-six children who took part in the study were
administered the SCAN-C test for auditory processing disorders, as discussed in more
detail below. The SCAN-C test identified one child as “disordered” (a composite score of less than 70). However, a subsequent full APD assessment at the UoCSHC revealed the child to have normal auditory processing ability.

Consequently, all twenty-six children from St Teresa’s School who were provided with parental consent to take part in the study were placed in the “children with normal auditory processing” group. Therefore, no children with APD were recruited for this stage of the study and consequently, the comparison between the performance of children with and without APD could not be performed.

Children with normal auditory processing

As discussed above, the participants for this group consisted of twenty-six children from St Teresa’s School who were provided with parental consent to take part in the study, and six children who were on the hospital waiting list who had accepted the offer to be tested at the UoCSHC. As discussed above, none of the children from either source were diagnosed as having APD, and therefore all of the children were placed into the “children with normal auditory processing” group.

Adults with normal auditory processing

The adult participants were recruited from the faculty of the Department of Communication Disorders at the University of Canterbury, as well as from the local community. Participants were approached and invited to participate in the study on a voluntary basis.

Participant summary

To summarise, no children with APD were recruited for this stage of the study. Thirty-two children were recruited for the “children with normal auditory processing” group and twenty-three adults were recruited for the “adults with normal
auditory processing” group. The age range of the child participants was 8 to 11 years with a mean age of 9.9 years (± 1.3 years). The age range of the adult participants was 18 to 55 years with a mean age of 29.8 (± 9.5 years). The male to female ratio was 1.36:1, and 1.8:1 for the child and adult participants, respectively.

**Test Procedure**

The twenty-six children from St. Teresa’s School who took part in the study were tested at the school in an isolated test room (the school “sick bay”) by the one examiner. The remaining children and all of the adult participants were tested in an audiological booth at the UoCSHC by the same examiner.

**UC MAST test procedure**

Three different versions of the UC MAST test were conducted for each participant. The first version of the UC MAST sought the 50% binaural threshold, while the second and third versions of the UC MAST sought the 71% and 50% monaural thresholds respectively. For both the 71% and 50% monaural versions, data was obtained for the right and left ears separately.

**Binaural 50% UC MAST**

The binaural 50% UC MAST was implemented at the beginning of the test procedure as a practice run. This version of the UC MAST was used to familiarise the participants with the task and reduce the impact of the learning effect on the subsequent monaural trials. Therefore, the binaural 50% UC MAST results are presented in this study for completeness only, as the validity of the results were likely to be confounded by a learning effect.
Monaural 50% and 71% UC MAST

The monaural 50% and 71% versions of the UC MAST were implemented to obtain an estimate of the psychometric function for performance of adults and children with normal auditory processing ability on the UC MAST.

Test-Retest Reliability

Additionally, the performance on the monaural 71% UC MAST for each adult participant (n=23) and the majority of child participants (n=30 of 32) were analysed across repeated trials. The purpose of these repeated trials was two-fold. First, to determine the test-retest reliability of the measure and second, to determine whether the changes made to the UC MAST as a result of the pilot study had been successful in eliminating the influence of the learning effect.

Each participant performed the 71% UC MAST twice for each ear under identical conditions with a test-retest interval of one week between tests. The right ear was tested first during each test session for all of the participants. To determine the test-retest reliability of the measure for each ear, the threshold score obtained from the first test session was compared against the threshold score of the same ear from the second session, i.e., R1-71 v R3-71 and L2-71 v L4-71.
UC MAST Test Order

Therefore, participants during this stage of the study were tested on the UC MAST in the following order:

i) 50% UC MAST: Binaural (B1-50).

ii) 71% UC MAST: Right ear - Trial #1 (R2-71).

iii) 71% UC MAST: Left ear – Trial #1 (L3-71).

iv) 50% UC MAST: Right ear (R4-50).

v) 50% UC MAST: Left ear (L5-50).

*Test-retest interval (1 week).*

vi) 71% UC MAST: Right ear - Trial #2 (R6-71).

vii) 71% UC MAST: Left ear – Trial #2 (L7-71).

SCAN-C Test Procedure:

As mentioned previously, all child participants underwent a screening for auditory processing disorder using the commercially available SCAN-C test battery. The four subtests of the SCAN-C test were administered to the children via the same transducers used for the UC MAST. The SCAN-C compact disc contained the pre-recorded test instructions, subtest practice items, and actual test items. Clarification of test instructions was provided only when necessary.

The SCAN-C compact disc was played in the CD player of the laptop computer, which was connected through the audiometer for calibration purposes. The calibration tone on track 1 was adjusted to 0 VU for channels 1 and 2 of the audiometer. The attenuator of both audiometer channels was set to 60 dB HL and the

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9 Five of the 23 participants performed the low-pass filter UC MAST 50% Binaural last – i.e., (B7-50).
track corresponding to the appropriate test was selected. During testing, each child was seated face-to-face with the examiner, and the scoring form was out of the child’s view. As recommended, breaks were not provided, nor the CD stopped once a subtest had begun (Keith, 2000c). If a child was not able to respond within the time period provided, the test continued and any non-response was marked as incorrect.

**Results**

**Overview of results**

The results are presented in three sections. Section one presents test-retest reliability results for the 71% threshold-seeking function of the UC MAST, while section two provides and compares UC MAST results for the adult and child participants for all versions of the test to determine the effect of maturation on UC MAST performance. The final section presents correlation analyses between the performance of the child participants on the UC MAST and SCAN-C test for auditory processing.

**Section One: Test-Retest Reliability**

The individual results for the performance of each adult and child participant on the monaural 71% UC MAST are listed in Table II-2 and Table II-3 respectively (in Appendix II). The individual data for the adult and child participants are also displayed graphically in separate scattergrams in Figure 14 and Figure 15 on pages 92 and 93 respectively.

The scattergrams display the reliability of a participant’s performance on the UC MAST by plotting their threshold score from the first test session against their threshold score from the second test session. Each symbol (right ear = circle, left ear = diamond) depicts one pair of scores. A line of best fit was obtained through the data
(right ear = dotted line, left ear = dashed line) and a linear reference line (solid line) indicates where all the data points would have fallen if the correlation were perfect (i.e., an $r$ of +1.00). If the test was 100% reliable, then both administrations of the UC MAST would yield identical thresholds and the mean slope of the line of best fit would equal the reference line, with a y-intercept of 0. Therefore, how close the slope of the line of best-fit approximated 1.0 (the reference line) indicated the agreement between the thresholds scores obtained from each test session.

Additionally, the mean right and left ear 71% UC MAST thresholds for the adult and child groups for each test session are displayed in Figure 16 on page 94. Each bar indicates the mean performance of the participants for each trial, and the error bar represents one standard deviation of the measure for each trial. Statistical analysis was performed to establish if the threshold scores from the first trial were significantly different from those of the second trial to determine the precision of the measure with repeated administrations of the test.

**Adult participant test-retest reliability**

For the adult participants, the first and second UC MAST test sessions yielded a mean 71% UC MAST right ear threshold of 698 Hz ($\pm$ 205 Hz) and 655 Hz ($\pm$ 175 Hz), respectively. For the left ear, the mean 71% UC MAST thresholds for the first and second test sessions were 670 Hz ($\pm$ 175 Hz), and 669 Hz ($\pm$ 172 Hz), respectively. There was no significant difference between the threshold scores of the first and second trials for either the right$^{10}$ or left$^{11}$ ear. However, the absolute mean

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$^{10}$ Dependent $t$ test [$t(22) = 1.93, p = 0.07$].

$^{11}$ Dependent $t$ test [$t(22) = 0.075, p = 0.9$].
Test-retest comparison for the right and left ears of the adult participants on the 71% UC MAST

![Graph showing test-retest comparison for right and left ears.]

Figure 14: A comparison of the right and left ear 71% UC MAST threshold scores obtained by each adult participant over two consecutive trials that were conducted one week apart. The lines of best fit for the individual data points are displayed for each ear.
Test-retest comparison for the right and left ears of the child participants on the 71% UC MAST

Figure 15: A comparison of the right and left ear 71% UC MAST threshold scores obtained by each child participant over two consecutive trials that were conducted one week apart. The lines of best fit for the individual data points are displayed for each ear.
Figure 16: Right and left ear mean monaural 71% UC MAST threshold scores and standard deviations for the adult and child participants with normal auditory processing over two test sessions conducted with a test-retest time interval of one week.
difference of 43 Hz (± 106 Hz) between the first and second trials of the right ear was much larger than the absolute mean difference of 1 Hz (± 91 Hz) between the two trials of the left ear, as displayed above in Figure 16.

There was a strong correlation between the thresholds obtained by each participant during the first and second test sessions for both the right\textsuperscript{12} and left\textsuperscript{13} ears, as displayed in Figure 14 on page 92. Because a lower frequency indicates a better performance, a slope of less than one in Figure 14 indicates an improvement in test scores between trials. The slope of the line of best fit approximated 0.7 and 0.9 for the right and left ears respectively. This result, along with a correlation coefficient of 0.86 for both ears and no significant difference between the threshold scores for repeated test administrations, indicates a good agreement between the test-retest values and high UC MAST reliability for the adult participants.

**Child participant test-retest reliability**

For the child participants, trial one and two of the UC MAST for the right ear yielded a mean 71\% threshold of 1248 Hz (± 309 Hz), and 1007 Hz (± 296 Hz) respectively. The performance on the second trial was significantly\textsuperscript{14} better than that of the first trial. There was a moderate correlation\textsuperscript{15} between the thresholds of the first

\textsuperscript{12} Pearson correlation coefficient of $r = 0.855$, $p < 0.001$, indicating strong reliability; Coefficient of determination $R^2 = 0.73$.

\textsuperscript{13} Pearson correlation coefficient of $r = 0.862$, $p < 0.001$, indicating strong reliability; Coefficient of determination $R^2 = 0.74$.

\textsuperscript{14} Wilcoxon Signed Rank Test $W=309$, $T_+ = 78$, $T_- = -387$, $p = 0.002$.

\textsuperscript{15} Pearson correlation coefficient of $r = 0.37$, $p < 0.05$, indicating moderate reliability; Coefficient of determination $R^2 = 0.13$. 
and second trials, as displayed in Figure 15 on page 93. The slope of the line of best fit approximated 0.4 indicating a moderate agreement between the test-retest values. These results suggest that repeated administration of the UC MAST cause a significant improvement in child performance on this test, but that the degree of improvement in children is quite variable between participants.

For the left ear, the first and second UC MAST test sessions yielded a mean 71% threshold of 1038 Hz (± 248 Hz), and 1010 Hz (± 243 Hz) respectively. Unlike for the right ear, the difference in threshold scores of the two trials was not significant\(^{16}\), with an absolute mean difference of 28 Hz (± 229 Hz). A strong correlation\(^{17}\) was found between the first and second trials, as shown in Figure 15 on page 93. The slope of the line of best fit approximated 0.6, indicating a stronger agreement between test-retest values than for the right ear.

The significant improvement in test performance shown by the child participants on the second trial of the UC MAST for the right ear suggests the presence of a probable learning effect, even more so when compared with the consistent results of the left ear. As shown in Figure 16 on page 94, the mean threshold for the second trial of the right ear is clearly better than the mean threshold for the first trial, and more consistent with the thresholds obtained for both trials of the left ear.

A similar finding was also evident for the adult participants, as shown in Figure 16 on page 94. The paired t-test indicated no significant improvement in mean

\(^{16}\) Dependent t test \([t(29) = 0.67, p = 0.51]\).

\(^{17}\) Pearson correlation coefficient of \(r = 0.57, p < 0.005\), indicating strong reliability; Coefficient of determination \(R^2 = 0.32\).
right ear test scores from trial one to trial two. However, the mean threshold score for
the second trial of the right ear is clearly better than that of the first trial and more
consistent with the threshold scores from both trials of the left ear. These results
suggest that despite the inclusion of a binaural practice test at the beginning of the
first test session, a learning effect is still evident throughout the course of the first test
session – although this effect is more evident in child participants than adult
participants.

**Determination of the severity of the learning effect**

To better assess the severity of the learning effect, the mean threshold scores
obtained for all participants were compared in order of the trials conducted (R1-71 vs.
L2-71 vs. R3-71 vs. L4-71) and irrespective of the ear tested. The mean 71% UC
MAST thresholds obtained by all the participants for each consecutive trial are listed
on the following page in Table 2 and are displayed graphically in Figure 17 on page
99.

**Influence of learning effect on the child participants**

As is clearly visible in Figure 17 on page 99, the child participants showed a
significant improvement in test performance between the first and second trials of the
71% UC MAST. However, subsequent administrations of the UC MAST produced no
further significant improvements in test performance.

As listed in Table 2 over the page, the mean absolute difference between each
administration of the UC MAST decreased with each successive trial of the test.
Table 2: Mean 71% UC MAST thresholds for the child and adult participants across four consecutive trials of the test and the mean absolute difference between each trial.

<table>
<thead>
<tr>
<th>Number of Trial</th>
<th>Child Participants</th>
<th>Adult participants</th>
<th>Absolute Mean Difference (Hz) (Compared to previous trial)</th>
<th>Absolute Mean Difference (Hz) (compared to previous trial)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Threshold (Hz)</td>
<td>Range (Hz)</td>
<td>NA</td>
<td>698 (±205)</td>
</tr>
<tr>
<td>Trial #1 (R1)</td>
<td>1248 (±309)</td>
<td>716 to 1860</td>
<td>210(^{18})** (±291)</td>
<td>670 (±175)</td>
</tr>
<tr>
<td>Trial #2 (L2)</td>
<td>1038 (±248)</td>
<td>572 to 1599</td>
<td>30(^{20}#) (±260)</td>
<td>656 (±175)</td>
</tr>
<tr>
<td>Trial #3 (R3)</td>
<td>1007 (±296)</td>
<td>579 to 1757</td>
<td>3(^{22}#) (±270)</td>
<td>669 (±173)</td>
</tr>
<tr>
<td>Trial #4 (L4)</td>
<td>1010 (±243)</td>
<td>593 to 1506</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: All values are in Hertz. Values in brackets are standard deviations
** * p < 0.001
# not significant at the p=0.05 level

\(^{18}\) Dependent t test \([t(29) = 3.96, p = <0.001]\].
\(^{19}\) Dependent t test \([t(29) = 1.1, p = <0.28]\].
\(^{20}\) Dependent t test \([t(29) = 0.65, p = <0.52]\].
\(^{21}\) Dependent t test \([t(29) = 0.57, p = <0.58]\].
\(^{22}\) Dependent t test \([t(29) = 0.06, p = <0.95]\].
\(^{23}\) Dependent t test \([t(29) = 0.54, p = <0.59]\].
Performance of all participants on the 71% UC MAST over four consecutive trials.

Figure 17: Mean 71% UC MAST thresholds scores for the child (circles) and adult (squares) participants over four consecutive trials of the test. Brackets represent the standard deviation of the measure.
Although the absolute mean difference of 238 Hz (±257 Hz) between the first (R1-71) and last trial (L4-71) of the 71% UC MAST was significant\textsuperscript{24}, the absolute mean difference of 28 Hz (±229 Hz) between the second (L2-71) and fourth trials (L4-71) was not statistically significant\textsuperscript{25}. This result suggests that once a learning effect has reached a plateau, the threshold scores obtained by the children are consistent for repeated administrations of the test.

**Influence of learning effect on the adult participants**

As indicated in Table 2 on page 98, there was no significant improvement in adult test performance between any of the administrations of the UC MAST. Overall, the mean absolute difference of 30 Hz (±103 Hz) between the first (R1-71) and fourth (L4-71) trials of the 71% UC MAST was not statistically significant\textsuperscript{26}. This result, when compared with the findings of the pilot study, suggest the changes made to the UC MAST for this stage of the study (the inclusion of a binaural practice run and an increased number of practice reversals) were effective at diminishing the learning effect for the adult participants.

In comparison to the child participants, the result also suggests that adult participants became familiar with the UC MAST more quickly than their child counterparts, as the learning effect had reached a plateau immediately following the binaural practice task for the adult group.

Figure 17 on page 99 illustrates two important features of the data. First, the mean 71% UC MAST threshold scores obtained by the adults participants were

\textsuperscript{24} Dependent $t$ test [$t(29) = 5.08$, $p = <0.001$].

\textsuperscript{25} Dependent $t$ test [$t(29) = 0.67$, $p = 0.51$].

\textsuperscript{26} Dependent $t$ test [$t(29) = 1.39$, $p = <0.18$].
clearly better than the scores obtained by the child participants. Second, adults were more consistent across the repeated test administrations than the child participants. The standard deviation of each trial is represented on the graph by the length of the error bars. Therefore the inter-subject variability of the measure for the adult participants was lower than the variability for the child participants. Consequently, the adult participants were more consistent than the child participants across the four trials.

To summarise, the results for this section suggest high test-retest reliability for the UC MAST once the initial learning effect has diminished. That is, the learning effect appears to have reached a plateau after the first administration of the UC MAST, which for each participant - was the first trial of the right ear. Further, the results indicate that a participant may require a practice session of longer duration, so that a definite plateau is reached prior to the commencement of the actual testing. This would increase the confidence that the threshold obtained from a single administration of the UC MAST is truly indicative of the participant’s actual threshold.

**Section Two: Results for the adult and child participants**

**50% UC MAST results**

A comparison between the monaural and binaural conditions was never an aim of the current study. The main aim of testing the adults and children was to examine their monaural performance on the UC MAST. However, during the design phase of the programme, it became apparent that a participant’s test performance on the UC MAST improved markedly with a repeated administration. Therefore, as mentioned previously in the method section, the binaural test was included in the study to provide a practice session for the participants, prior to the right and left ears being tested independently. The aim of the binaural condition was to familiarise the
participant with the procedure, so that the results for the monaural conditions were more indicative of the participant's true threshold. The fact that the binaural runs were performed first means that there was a significant learning effect which limited the comparison of the binaural and monaural conditions. However for completeness of the study, this comparison appears below.

For the majority of adult and child participants, the 50% UC MAST threshold was obtained binaurally, as well as for each ear independently. The monaural 50% threshold refers to the average of the 50% UC MAST thresholds for both the right and left ears. The mean 50% UC MAST results for both the child and adult participants are displayed in the first four columns of Figure 18 on page 103. The individual results for each adult and child participant are listed in Table II-4 and Table II-5 in Appendix II.

**Adult binaural 50% UC MAST and monaural 50% UC MAST threshold results**

Overall, the mean 50% monaural threshold for the adult participants (n=23) was 419 Hz (±108 Hz), while the mean 50% binaural threshold was 522 Hz (±157 Hz). The threshold corner frequency for the binaural condition was significantly27 higher than for the monaural condition, by an absolute mean difference of 103 Hz (±119 Hz). Performance on the monaural test correlated28 strongly with performance on the binaural test as shown in Figure 19 on page 106.

While this result appears to indicate that participants performed better on the monaural test than the binaural test, the apparent monaural advantage is probably a

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27 Dependent t test \[t(22) = 4.14, p = <0.001\].

28 Pearson correlation coefficient \(r = 0.65, p < 0.001\), indicating strong reliability; Coefficient of determination \(R^2 = 0.48\).
Figure 18: Mean UC MAST threshold results for the adult and child participants.
reflection of the learning effect and the fact that the majority of the participants performed the binaural test before the monaural tests as discussed below.

The 50% binaural condition of the UC MAST was the first attempt (B1-50) at the UC MAST for the majority of the adult participants (n=18), whereas the 50% monaural conditions represented their fourth (R4-50) and fifth (L5-50) attempts at the test, as outlined in the “UC MAST test order” section of the method.

The remaining five participants were administered the binaural test (B7-50) after they had performed all of the monaural test conditions, due to a modification of the method after commencement of this stage of the study. Therefore, the latter group had already become familiar with the UC MAST prior to the binaural task and this previous exposure to the UC MAST for this group resulted in improved binaural thresholds.

The two groups are clearly represented by square and round symbols in Figure 19 on page 106. The results clearly indicate a better result on the binaural test when performed after the monaural test.

For the five participants who performed the binaural test last, the mean 50% binaural and 50% monaural UC MAST threshold scores were 347 Hz (±60 Hz) and 332 Hz (±106 Hz) respectively. The mean absolute difference of 15 Hz (±87 Hz) between the binaural and monaural conditions was not significant\(^\text{29}\). In contrast, for the participants who performed the binaural test first, the mean binaural 50% and monaural 50% UC MAST threshold scores were 570 Hz (±140 Hz) and 443 Hz (±98

\(^{29}\) Dependent \(t\) test \([t(4) = 0.39, p=0.72]\).
Hz) respectively. These participants performed significantly\(^{30}\) better on the 50% monaural condition by an absolute mean difference of 127 Hz (±117 Hz).

Although the result for the five participants who performed the binaural test last continues to suggest that the monaural task was easier than the binaural task, the slightly better monaural performance may have been due to the advantage of the learning effect being reduced by the lengthy time interval between the administration of the monaural tests and the subsequent administration of the binaural test.

To summarise, probable order and learning effects confounded a comparison of the monaural and binaural results for the adult participants. Again, it must be emphasized that this analysis was conducted for completeness only as the binaural trial was implemented as a practice run in an effort to reduce the learning effect determined during the pilot study of the UC MAST. However, as expected a strong correlation was shown between the results obtained by participants on both tests.

**Child binaural 50% UC MAST and monaural 50% UC MAST threshold results**

Overall, the mean monaural (n=31) 50% UC MAST and binaural (n=32) 50% UC MAST thresholds for the child participants were 688 Hz (± 193 Hz) and 951 Hz (± 270 Hz) respectively. The threshold corner frequency for the binaural condition was significantly\(^{31}\) higher than for the monaural condition by an absolute mean difference of 240 Hz (± 210 Hz).

As with the adult participants, the UC MAST test order probably played a role in determining the results. For every child participant, the 50% binaural UC MAST

\(^{30}\) Dependent \(t\) test \([t(17) = 4.61, p=0.<0.001]\).

\(^{31}\) Dependent \(t\) test \([t(29) = 6.24, p = <0.001]\).
Comparison of the mean monaural 50% and binaural 50% thresholds obtained by each adult participant on the UC MAST

Figure 19: Comparison of 50% binaural UC MAST and 50% monaural (left ear + right ear) UC MAST thresholds. The squares represent five adult participants who performed the 50% binaural UC MAST in a different test order to the other participants.
was administered first (B1-50) and the right and left monaural 50% tasks were the fourth (R4-50) and fifth (L5-50) administrations of the task respectively.

Performance on the monaural test correlated\textsuperscript{32} moderately with performance on the binaural test as shown in Figure 20 on page 109. This result shows more variation than with the adult participants and also indicates that children who had difficulty with the first (binaural) task were only moderately likely to have difficulty with the subsequent (monaural) task, and vice versa.

To summarise, comparison of the binaural and monaural results in children were confounded by the same practice effect observed in the adult participants. However, the higher variability of the child results meant that the correlation between the results obtained by the participants on both tests was reduced. Practice effects are seen on most measures (Dikmen \textit{et al.}, 1999; Collie \textit{et al.}, 2003), however it was still surprising to note that both the adult and child participants performed better on the monaural condition than on the binaural condition, despite long recognition of the binaural advantage for understanding speech in adverse listening conditions (Nabelek & Robinson, 1982; Helfer, 1994). Therefore, test order significantly impacted the UC MAST results, as shown by the order in which the binaural and monaural tests were conducted. The need for the binaural practice session now appears justified, as the majority of participants recorded better thresholds for the monaural condition than the binaural condition despite the fact that listening binaurally should have been easier than using separate ears, therefore suggesting the presence of the practice effect.

\textsuperscript{32} Pearson correlation coefficient $r = 0.55$, $p < 0.005$, indicating strong reliability; Coefficient of determination $R^2 = 0.31$. 
Comparison of adult and child binaural 50% UC MAST and monaural 50% UC

MAST threshold results

As shown in Figure 18 on page 103, the adult participants performed significantly better than the child participants on both the 50% binaural\textsuperscript{33} and 50% monaural\textsuperscript{34} versions of the UC MAST by an absolute mean difference of 429 Hz and 269 Hz respectively.

Adult right ear and left ear 50% UC MAST threshold results

As shown in Figure 18 on page 103, the mean 50% UC MAST threshold scores for the right and left ears of the twenty three adult participants were 391 Hz (± 107 Hz) and 447 Hz (± 125 Hz) respectively, producing an absolute mean difference of 56 Hz (± 87 Hz), which was statistically significant\textsuperscript{35}. As displayed in Figure 21 on page 111, there was a strong correlation\textsuperscript{36} between the ability of a participant to perform the right ear task, and their ability to perform the left ear task, as would be expected. However the right ear performance on the task was significantly better than the left ear performance, consistent with the presence of hemispheric dominance, whereby a right ear advantage indicates that language processing is appropriately established in the left cerebral hemisphere (Keith, 2000c).

\textsuperscript{33} Independent groups t test \( t(53) = 6.82, p < 0.001 \).

\textsuperscript{34} Independent groups t test \( t(51) = 6.0, p < 0.001 \).

\textsuperscript{35} Dependent t test \( t(22) = 3.08, p= 0.006 \).

\textsuperscript{36} Pearson correlation coefficient \( r = 0.73, p < 0.001 \) indicating a strong positive relationship; Coefficient of determination \( R^2 = 0.57 \).
Comparison of the mean 50% monaural and 50% binaural thresholds obtained by each child participant on the UC MAST

Figure 20: Comparison of 50% binaural UC MAST and 50% monaural (left ear + right ear) UC MAST thresholds for the child participants.
Although it is thought that hemispheric dominance for language and the presence of a right ear advantage diminishes as the interhemispheric pathway (corpus callosum) matures (Cherry, 1953; Studdert-Kennedy & Shankweiler, 1970), the small but significant absolute mean difference in these results may suggest that this right ear advantage still exists in adult participants to a significant degree.

Child right ear and left ear 50% UC MAST threshold results

The mean 50% UC MAST threshold scores for the right ear and left ears were 630 Hz (± 235 Hz) and 636 Hz (± 187 Hz) respectively, as shown in Figure 18 on page 103. The absolute mean difference of 4 Hz (± 170 Hz) was not significant. As displayed in Figure 21 over the page, there was a strong correlation between the independent performances for each ear. These results indicate that the threshold score a child obtained for one ear on the UC MAST was indicative of the performance for their opposite ear as there was no significant ear advantage. The larger standard error of the means obtained by child participants (33.66 Hz for child participants vs. 21.40 Hz for adult participants) indicates that the test (when performed by children) may not be sensitive enough to reveal the presence of the ear advantage that was seen in adult participants, and which has shown to be present in children (Keith, 2000c).

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37 Mann-Whitney Rank Sum Test \[ T = 883.5 \ n(\text{small}) = 30, n(\text{big}) = 30, P = 0.65. \]

38 Pearson correlation coefficient \( r = 0.70, p < 0.001 \), indicating strong reliability;

Coefficient of determination \( R^2 = 0.48. \)
Comparison of right and left ear 50% UC MAST thresholds for all participants

![Graph showing comparison of right and left ear 50% UC MAST thresholds for all participants.]

**Figure 21:** Comparison of the right and left ear 50% UC MAST thresholds for both the adult and child participants.
71% UC MAST results

For the 71% UC MAST, the participant’s left and right ears were tested monaurally. As mentioned previously, both the adult and child participants underwent two separate 71% UC MAST trials for each ear. The original intention was to the average the individual results for both trials to produce a mean individual threshold for each ear. However, as discussed in section one, a significant learning effect influenced the results for the first trial of the right ear (R2-71) for the child participants, as displayed in Table 2 on page 98.

Furthermore, although no significant learning effect was identified for the adult participants on the 71% UC MAST for either ear, the absolute mean difference between trials was the lowest for the third (R6-71) and fourth (L7-71) trials of the 71% UC MAST, as listed in Table 2 on page 98.

Consequently, only the 71% threshold results from the second test session for each ear (R6-71 and L7-71) are used to represent the 71% UC MAST thresholds scores for both the adult and child participants in this study.

The right and left ear thresholds were also combined to produce an overall 71% monaural threshold for each participant. The mean right ear, left ear and monaural 71% UC MAST results for both the adult and child participants are displayed in the last three columns of Figure 18 on page 103. The individual 71% monaural results for each adult and child participant are listed in Table II-6 in Appendix II.
Adult monaural 71% UC MAST threshold results

The mean monaural 71% threshold for the adult participants (n=23) was 662 Hz (± 164 Hz). As expected, the 71% threshold was significantly\(^{39}\) higher than the 50% monaural threshold by a mean absolute difference of 243 Hz (± 126 Hz), as shown in Figure 18 on page 103. This result is largely due to the increased spectral content required to enable the participant to score 71% of presentations correctly, rather than only 50%.

Figure 22 on page 114 is a scattergram that compares both the 50% and 71% thresholds recorded by each adult participant (n=23) on the UC MAST. The strong correlation\(^{40}\) between the 50% and 71% thresholds indicate that an adult’s ability to perform the test is consistent despite the change in threshold target and that the result from one threshold test can reliably be used to predict their performance for the other threshold test. This result has implications for the clinical applications of adaptive tests using these methods, as discussed later.

Child monaural 71% UC MAST threshold results

The mean monaural 71% threshold for the child participants (n=31) was 1009 Hz (± 235 Hz). As shown in Figure 18 on page 103, the 71% UC MAST threshold was significantly\(^{41}\) higher than the 50% monaural threshold by a mean absolute difference

\[^{39}\text{Dependent }t\text{ test }[t(23) = 9.25, p = <0.001].\]

\[^{40}\text{Pearson correlation coefficient }r = 0.64, p < 0.001\text{ indicating a strong positive relationship; Coefficient of determination }R^2 = 0.47.\]

\[^{41}\text{Dependent }t\text{ test }[t(28) = 7.70, p = <0.001].\]
Comparison of monaural 50% UC MAST and monaural 71% UC MAST thresholds for all participants

Figure 22: Comparison of the monaural 50% and monaural 71% UC MAST thresholds for both the adult and child participants.
of 300 Hz (± 210 Hz). There was a moderate correlation\(^{42}\) between the 50% and 71% thresholds recorded by each child participant, as displayed in Figure 22 above.

As expected, this result suggests that a child participant’s performance on the 50% UC MAST was better than their performance on the 71% threshold test because of the requirement to get less words correct, and that their performance on one test can only moderately predict their performance on the other.

**Adult right ear and left ear 71% UC MAST threshold results**

As shown earlier in Figure 18, the mean 71% threshold scores for the right and left ears of the adult participants (n=23) were 656 Hz (± 175 Hz) and 669 Hz (± 173 Hz), respectively. Unlike for the 50% UC MAST, this disparity was not significant\(^{43}\) with an absolute mean difference between the ears of 13 Hz (± 115 Hz). This result suggests that the interhemispheric dominance in adults may not be evident until the CANS is stressed by a difficult task.

As mentioned above, the low-pass filter corner frequency at which a score of 71% was obtained was significantly higher than for the 50% condition. Therefore, because spectral information is available to the CANS for auditory closure, it is likely that this results in less stress being placed on the CANS. As a result, the right ear advantage that became apparent during the 50% threshold tests, was not apparent during the 71% threshold tests, as the CANS was not taxed enough for the advantage

\(^{42}\)Pearson correlation coefficient of \( r = 0.48, p < 0.01\), indicating moderate reliability;

Coefficient of determination \( R^2 = 0.48\).

\(^{43}\)Dependent \( t \) test \([t(22) = 0.55, p=0.59]\).
to become visible. A strong correlation\textsuperscript{44} between right and left sides is visible in Figure 23 on page 118, consistent with the lack of a statistically significant difference between the 71\% thresholds of the right and left ears.

**Child right ear and left ear 71\% UC MAST threshold results**

When the right and left ear performance on the 71\% UC MAST threshold task were examined, the mean thresholds for the right and left ears were 1007 Hz (± 296 Hz), and 1010 Hz (± 243 Hz), respectively. The absolute mean difference between the ears of 3 Hz (± 270 Hz) was not significant\textsuperscript{45}. A strong correlation\textsuperscript{46} between the individual results was exhibited, as displayed in Figure 23 on page 118.

This result suggests that a child’s performance with their right ear is indicative of their performance in their left ear. Although previous studies have shown there to be a right ear advantage in children up to 11 years of age (Keith, 2000c), our results did not show this advantage.

**Comparison of adult and child monaural 71\% UC MAST threshold results**

As is clearly visible in Figure 18 on page 103, the adult participants performed significantly\textsuperscript{47} better than the child participants on the 71\% monaural UC MAST by an absolute mean difference of 430 Hz. These results, combined with the 50\% UC

\textsuperscript{44} Pearson correlation coefficient $r = 0.78$, $p < 0.001$ indicating a strong positive relationship; Coefficient of determination $R^2 = 0.61$.

\textsuperscript{45} Dependent $t$ test [$t(29) = 0.062$, $p < 0.095$].

\textsuperscript{46} Pearson correlation coefficient of $r = 0.51$, $p < 0.005$, indicating strong reliability; Coefficient of determination $R^2 = 0.26$.

\textsuperscript{47} Independent groups $t$ test [$t(53) = 7.48$, $p < 0.001$].
MAST results, indicate that ability to perform auditory closure on low-pass filtered speech is significantly effected by the maturity of the CANS. The thresholds for each participant on the both the monaural 50% and monaural 71% UC MAST are displayed as a function of age in Figure 24 on page 120. The trend lines on the graph show a gradual decrease in the threshold score as the age of the participant increases for both the 50% and 71% condition. Clearly, the adult participants performed better than children at filling in the missing information from words in which part of the acoustic spectrum was absent.

**UC MAST results by age of child participant**

Figure 25 on page 121 displays the data in more detail for the child participants by showing the mean thresholds for each UC MAST test type for the seven to eleven year old age group. The mean UC MAST threshold scores for each age group are listed in Table 3 on page 122.

Overall, there was no significant improvement in test performance with age on the binaural 50% UC MAST\(^{48,49,50,51}\), the monaural 50% UC MAST\(^{52,53,54,55}\) or the

\(^{48}\) 7 year olds v 8 year olds: Independent groups \(t\) test \([t(5) = 1.77, p = 0.14]\).

\(^{49}\) 8 year olds v 9 year olds: Independent groups \(t\) test \([t(12) = 2.15, p = 0.053]\).

\(^{50}\) 9 year olds v 10 year olds: Independent groups \(t\) test \([t(16) = 0.45, p = <0.66]\).

\(^{51}\) 10 year olds v 11 year olds: Independent groups \(t\) test \([t(16) = 0.29, p = <0.78]\).

\(^{52}\) 7 year olds v 8 year olds: Independent groups \(t\) test \([t(4) = 0.084, p = <0.94]\).

\(^{53}\) 8 year olds v 9 year olds: Independent groups \(t\) test \([t(10) = 1.33, p = <0.22]\).

\(^{54}\) 9 year olds v 10 year olds: Independent groups \(t\) test \([t(15) = 2.07, p = <0.056]\).

\(^{55}\) 10 year olds v 11 year olds: Independent groups \(t\) test \([t(14) = 1.74, p = <0.10]\).
Comparison of right and left ear 71% UC MAST thresholds for all participants

Figure 23: Comparison of the right and left ear 71% UC MAST thresholds for both the adult and child participants.
71% condition\textsuperscript{56, 57, 58, 59}. Although not significantly, the mean 50% and 71% monaural threshold scores did improve as the children increased in age from seven years old to eleven years old, suggesting better test performance and that increased maturity of the CANS is associated with better auditory closure ability.

There was no significant\textsuperscript{60} difference between the performance of the seven year olds on the binaural and monaural 50\% test conditions, whereas the eight\textsuperscript{61} year olds, nine\textsuperscript{62} year olds, ten\textsuperscript{63} year olds and eleven\textsuperscript{64} year olds all performed significantly better on the monaural test, which as mentioned previously, was largely due to test order and subsequent practice effect. This result indicates that seven year olds may not learn as quickly as their counterparts, and therefore the practice effect was reduced in this age group.

\textsuperscript{56} 7 year olds v 8 year olds: Independent groups $t$ test [$t(5) = 0.58, p = <0.59]$.  
\textsuperscript{57} 8 year olds v 9 year olds: Independent groups $t$ test [$t(12) = 1.06, p = <0.31]$.  
\textsuperscript{58} 9 year olds v 10 year olds: Independent groups $t$ test [$t(16) = 0.53, p = <0.60]$.  
\textsuperscript{59} 10 year olds v 11 year olds: Independent groups $t$ test [$t(14) = 1.91, p = <0.078]$.  
\textsuperscript{60} Dependent $t$ test [$t(2) = 0.20, p = <0.86]$.  
\textsuperscript{61} Dependent $t$ test [$t(3) = 5.35, p = <0.013]$.  
\textsuperscript{62} Dependent $t$ test [$t(7) = 4.60, p = <0.002]$.  
\textsuperscript{63} Dependent $t$ test [$t(8) = 4.52, p = 0.002]$.  
\textsuperscript{64} Dependent $t$ test [$t(6) = 4.06, p = 0.007].
Figure 24: Performance of all participants on the 50% UC MAST and 71% UC MAST as a function of age.
Figure 25: A comparison of the 50% UC MAST & 71% UC MAST mean thresholds between the child participants by age (year).
Table 3: Mean UC MAST threshold scores for each age group. Values in brackets are standard deviations and all values are in Hertz.

<table>
<thead>
<tr>
<th>Age group / UC MAST test condition</th>
<th>7 years ( (n = 2) )</th>
<th>8 years ( (n = 5) )</th>
<th>9 years ( (n = 9) )</th>
<th>10 years ( (n = 9) )</th>
<th>11 years ( (n = 7) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binaural 50% (Hz)</td>
<td>768 (±89)</td>
<td>1248 (±360)</td>
<td>937 (±191)</td>
<td>890 (±247)</td>
<td>886 (±252)</td>
</tr>
<tr>
<td>Monaural 50% (Hz)</td>
<td>818 (±352)</td>
<td>792 (±356)</td>
<td>618 (±102)</td>
<td>739 (±134)</td>
<td>606 (±173)</td>
</tr>
<tr>
<td>Monaural 71% (Hz)</td>
<td>1296 (±264)</td>
<td>1168 (±265)</td>
<td>1010 (±268)</td>
<td>1078 (±271)</td>
<td>865 (±128)</td>
</tr>
</tbody>
</table>
Section Three: A comparison between the performance of the child participants on the UC MAST and SCAN-C test for auditory processing.

The results for each child participant on the SCAN-C test for auditory processing disorders are listed in Table II-7 (in Appendix II). The correlation analyses focus on Subtest 1 (Filtered words test) and Subtest 2 (Auditory figure ground test) of the SCAN-C test, as these subtests assess the same auditory closure skills as the UC MAST. The correlations were expected to be negative, as a better performance on both tests would give a higher score on the SCAN-C filtered words subtest and a lower threshold frequency on the UC MAST.

For the SCAN-C test, the raw scores are usually converted to a standard score based on the child’s age. This conversion compensates for development of auditory processing with age. However, as one of the aims of this study was an analysis of the effect of age on performance of the UC MAST, the UC MAST results were not adjusted for age. Therefore, the correlation analyses were performed using the raw scores of the SCAN-C test and the threshold scores of the UC MAST.

A correlation analysis was performed between the results for each of the three threshold conditions of the UC MAST test (Binaural 50%, Monaural 50% and Monaural 71%) and the appropriate results from the two SCAN-C subtests. The results are listed in Table 4 on page 124 below. No significant correlation was found between any of the UC MAST conditions and corresponding SCAN-C results.

As shown in Table II-7 (Appendix II), the mean standard deviation of the summed raw scores for both of the SCAN-subtests is around 9% of the mean. This result indicates little variation in the scores on these subtests, despite an age difference of up to four years between the child participants.
Table 4: Results of correlation analyses between the UC MAST and SCAN-C tests for the child participants

<table>
<thead>
<tr>
<th>UC MAST</th>
<th>SCAN-C</th>
<th>Pearson product-moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ear</td>
<td>Test</td>
<td>Ear</td>
</tr>
<tr>
<td>Binaural</td>
<td>50%</td>
<td>Both 1</td>
</tr>
<tr>
<td>Monaural</td>
<td>50%</td>
<td>Both 1</td>
</tr>
<tr>
<td>Right</td>
<td>50%</td>
<td>Right 1</td>
</tr>
<tr>
<td>Left</td>
<td>50%</td>
<td>Left 1</td>
</tr>
<tr>
<td>Monaural</td>
<td>71%</td>
<td>Both 1</td>
</tr>
<tr>
<td>Right Trial #1</td>
<td>71%</td>
<td>Right 1</td>
</tr>
<tr>
<td>Right Trial #2</td>
<td>71%</td>
<td>Right 1</td>
</tr>
<tr>
<td>Right Mean</td>
<td>71%</td>
<td>Right 1</td>
</tr>
<tr>
<td>Left Trial #1</td>
<td>71%</td>
<td>Left 1</td>
</tr>
<tr>
<td>Left Trial #2</td>
<td>71%</td>
<td>Left 1</td>
</tr>
<tr>
<td>Left Mean</td>
<td>71%</td>
<td>Left 1</td>
</tr>
<tr>
<td>Binaural</td>
<td>50%</td>
<td>Both 2</td>
</tr>
<tr>
<td>Monaural</td>
<td>50%</td>
<td>Both 2</td>
</tr>
<tr>
<td>Right</td>
<td>50%</td>
<td>Right 2</td>
</tr>
<tr>
<td>Left</td>
<td>50%</td>
<td>Left 2</td>
</tr>
<tr>
<td>Monaural</td>
<td>71%</td>
<td>Both 2</td>
</tr>
<tr>
<td>Right Trial #1</td>
<td>71%</td>
<td>Right 2</td>
</tr>
<tr>
<td>Right Trial #2</td>
<td>71%</td>
<td>Right 2</td>
</tr>
<tr>
<td>Right Mean</td>
<td>71%</td>
<td>Right 2</td>
</tr>
<tr>
<td>Left Trial #1</td>
<td>71%</td>
<td>Left 2</td>
</tr>
<tr>
<td>Left Trial #2</td>
<td>71%</td>
<td>Left 2</td>
</tr>
<tr>
<td>Left Mean</td>
<td>71%</td>
<td>Left 2</td>
</tr>
</tbody>
</table>
Displayed in Figure 26 on page 127 are the mean scores for each age group of the child participants on both of the SCAN-C subtests. In contrast to the variation shown with age on the UC MAST, there is little difference between the age groups of the children on the SCAN-C subtests. This result may indicate a ceiling effect in the scores for the SCAN-C filtered words subtest, which would support the use of an adaptive technique such as that implemented in the UC MAST.

A comparison between the 71% UC MAST threshold scores and the SCAN-C overall weighted score for each participant also produced a poor correlation.\textsuperscript{65}

\textsuperscript{65} Pearson correlation coefficient $r = 0.139$, $p > 0.050$, indicating poor reliability; Coefficient of determination $R^2 = 0.05$. 
SCAN-C Subtest 1 and Subtest 2 results by age

Figure 26: Mean SCAN-C test results by age group for the child participants
Discussion:

The purpose of the present study was to improve the filtered words test, a form of monaural low-redundancy assessment for the diagnosis of auditory processing disorders. It was proposed the UC MAST, through the use of an adaptive filter rather than a constant level filter, would remove the ceiling and floor effects inherent in constant level methods. It was proposed that the computerised, adaptive UC MAST would provide better efficiency and greater sensitivity for identifying a person’s auditory processing capabilities than the constant level methods used in the original filtered words tests. Ultimately, the UC MAST could prove a better alternative for discriminating between children with and without APD.

The following discussion will address the four hypotheses posed by analysing the performance on the UC MAST of the adult and child participants in this study, to determine if an adaptive version of the filtered words test has potential as a viable clinical assessment tool.

**Hypothesis 1: An adaptive computerised version of a low-pass filtered words test will produce results that are reliable over repeated administrations of the measure.**

Test-retest reliability of the UC MAST for this study was determined in two ways. First, a paired t-test was performed on the test and retest data to determine if there was a significant difference between the two administrations, and second, the relationship between the two administrations were expressed as a reliability coefficient. The latter analysis was performed using a Pearson product-moment correlation. A high correlation implied that a participant’s performance was stable
over repeated test administrations. According to (Ruscetta et al., 2005), an r value of \( \geq 0.7 \) is a respectable correlation to determine test-retest reliability.

For the adult participants, the paired t-tests revealed no significant test-retest differences for the right or left ears, and the correlation co-efficient was greater than 0.7 in both cases. Likewise, when analysed in terms of test order, no significant difference was found between consecutive trials. Therefore, it can be concluded that the results obtained for the adult participants indicate the UC MAST is a reliable measure and these findings support Hypothesis 1.

For the child participants, a significant difference was evident between the test and retest data of the right ear and the correlation between the two administrations of the UC MAST for the right ear was poor. The poor correlation between the two trials of the right ear suggest a significant factor caused a participant’s performance on the second trial to be substantially different from their performance on the first trial. In contrast, there was no significant difference between the test and retest data for the left ear, and the correlation between the two trials was moderately strong.

When analysed according to test order and irrespective of the ear tested, the absolute mean difference between each subsequent trial decreased. The mean thresholds of trial one and two were significantly different, however there was no significant difference between the remaining trials.

When analysed together, the above results suggest a learning effect influenced the right ear test-retest reliability results of the child participants on the UC MAST. In contrast to the adult participants, it appears that the child participants were still becoming familiar with the test procedure despite the binaural practice run (B1-50) and an extended learning effect contaminated the results of the first monaural test.
(R2-71). The learning effect appeared to reach a plateau by the second monaural trial (L3-71) and further improvement as a result of the learning effect was not significant.

Therefore, the UC MAST was a moderately reliable measure for the child participants once the learning effect had reached a plateau. This result suggests the need for an even longer practice session prior to the administration of the monaural tests. Therefore, it can be concluded that the results obtained for the child participants partially supported Hypothesis 1.

Overall, the relatively strong stability of the UC MAST threshold scores over repeated tests administrations is encouraging in terms of the clinical efficacy of the UC MAST. However, further modifications to the test procedure are required to ensure the learning effect does not contaminate the true threshold scores obtained by the participants.

**Hypothesis 2: An adaptive computerised version of a low-pass filtered words test will have greater efficiency and greater sensitivity in its ability to discriminate between children with and without APD, as there will be a significant difference in the scores on the filtered speech tests between subjects with APD compared to subjects without APD.**

As discussed in the method section, a lack of children with APD did not permit this hypothesis to be tested. From a clinical point of view, diagnosis of APD generally requires performance deficits on the order of two standard deviations poorer than the test mean on two or more of the tests in the APD battery (Chermak & Musiek, 1977). ASHA (2005a) suggest that if poor performance is observed on only one test, then a diagnosis of APD should be withheld unless the participant’s test score is at least three standard deviations poorer than the test mean.
Therefore, from the results of the current study, a clinically significant APD diagnosis for the child participants would be based on a 50% UC MAST threshold score of greater than 1074 Hz or a 71% UC MAST threshold score of greater than 1479 Hz, provided the child had also failed at least one other APD test from the test battery. For a clinically significant APD diagnosis based purely on the result from the UC MAST, the 50% and 71% UC MAST threshold scores would need to be greater than 1267 Hz and 1714 Hz respectively.

The clinically significant threshold scores for the five age groups of the child participants on the UC MAST are presented in Table 5 on page 132. The threshold scores for the diagnosis of APD are substantially lower as the age of the child increases. These results are consistent with improved auditory processing ability due to greater maturation of the CANS, as discussed in the following section.

It was proposed that children with APD would perform more poorly than children without APD provided the deficit was in their ability to use auditory closure. Auditory closure refers to the capacity of a listener to make use of intrinsic and extrinsic redundancy to fill in missing or degraded portions of the auditory signal to interpret the entire message.

The ability of a child to use their auditory closure skills was tested by the UC MAST as the signal was degraded and the child was required to decipher and then fill in the missing components of the auditory stimuli. To achieve auditory closure, a child relies on both the extrinsic and intrinsic redundancy of the signal to comprehend the stimuli.

Extrinsic factors include prior knowledge of the topic, knowledge of the phonemic aspects of speech, familiarity with the accent, familiarity with the rules of language and familiarity with the vocabulary being presented (Bellis, 2003). Intrinsic
factors refer to the repeated representation of the signal via complex networks throughout the CANS. A bilateral representation of each ear to each side of the brain contributes to the processing of information. This is achieved via a multiple mapping of pathways and crossings, interhemispheric connections, nuclear centres, and projections to primary and secondary cortical regions (Rintelmann, 1985).

As the stimuli for the UC MAST were the Australian recording of the NU-CHIPS word lists, familiarity with both the vocabulary and accent used in the recordings should have been irrelevant as the word lists were designed to be familiar to children as young as three years of age and the Australian accent is not too dissimilar to a New Zealand accent. Additionally, as the words were presented one at a time, there was no theme or knowledge of the topic for the children to use as an extrinsic aid.

Therefore, in terms of extrinsic redundancy, a child’s performance on the UC MAST was largely dependent on the degree of distortion in the acoustic signal that determined the amount of phonemic aspects available to the listener. Thus, as the child performed the task better, the adaptive procedure of the UC MAST removed more of the phonemic aspects of the signal and any remaining extrinsic aid. As a result, the child was required to rely more and more on the intrinsic redundancy of their CANS.

A child with an auditory closure processing deficit would display a breakdown in the intrinsic redundancy of the CANS, therefore reducing or eliminating the repeated representation of the incoming stimuli throughout the auditory pathways (Bellis, 2003). Therefore, better performance on the UC MAST reduces the extrinsic redundancy of the auditory stimuli, and a child with APD will not be able to perform
Table 5: Clinically significant UC MAST threshold scores for the diagnosis of APD using the data obtained from the current study. 2 SD and 3 SD refer to two and three standard deviations above the mean test score for the age group. 2 SD values would be used unless a child performs poorly on the UC MAST only, in which case 3 SD are the criteria for the diagnosis of APD.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>50% UC MAST</th>
<th>71% UC MAST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 SD (Hz)</td>
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the task as well as children without APD due to the reduced intrinsic redundancy of their CANS which diminishes their ability to achieve auditory closure.

**Hypothesis 3: Adult participants will perform significantly better on an adaptive computerised version of a low-pass filtered words test than children due to the maturational changes of the CANS that provide more efficient auditory processing.**

The results from the current study indicate that the mean monaural UC MAST thresholds were significantly better for the adult participants than for the child participants on both the 50% and 71% UC MAST. Consequently, hypothesis 3 was supported. These results are depicted graphically in Figure 27 on page 134, which plots the thresholds obtained by both the adult and child participants against the long term average speech spectrum.

As shown in Figure 27 over the page, the adult participants required less of the speech spectrum to be available than the child participants to correctly identify the same percentage of target words. Although it is largely recognised that a broad frequency region of about 125 to 8000 Hz is important for speech (Noordhoek et al., 1999), Figure 27 shows that the adult and child participants required only a small part of this speech spectrum to obtain percentage correct scores of 50% and 71%. As with previous studies (Patterson et al., 1982; Festen & Plomp, 1983; Dreschler & Plomp, 1985), a relationship was evident between reduced spectral resolution and speech intelligibility, i.e., both the adult and child participants required more spectral content to be present to obtain a 71% correct score than they required for a 50% score.
Figure 27: Performance of the adult (top) and child (bottom) participants on the 50% and 71% UC MAST. The 50% and 71% are represented by the solid and dashed lines, respectively. The lines intersect the long-term average speech spectrum and the area to the right of the lines represents the amount of spectral information missing from the stimuli. In comparison to the child participants, the adults performed better on both the 50% and 71% threshold tests, as indicated by the greater amount of spectral content missing from the stimuli.
There were significant age effects for the current study and the data from the current study suggests that the improvement in performance with increasing age was also associated with a reduction in the score variability, as demonstrated by the smaller standard deviations associated with increasing age of the participants. These results are consistent with those of Keith (2000a) who found a similar relationship between age, test score variability and auditory processing ability.

The improved performance with age on the UC MAST is consistent with the findings in the literature that suggest neuromaturation of some portions of the auditory system may not be complete until age twelve or later (Bellis, 2003). Additionally, the results from the current study suggest that the learning effect in the child participants was more prolonged than for the adults, and this may be due to the way in which children listen due to their lack of auditory closure experience. As suggested by Flexer (1999), children listen in a different way than adults as they do not possess the life experience and years of language that allow adults to fill in the missing information. Flexer (1999) suggests that the shortage of auditory closure experience means children require more complete, detailed auditory or acoustic information than adults, as reflected in the results of the UC MAST.

Apart from language, other factors such as attention, cognition, and executive function may have contributed to the relationship between age and UC MAST performance, making it more difficult for younger children to listen and to process auditory stimuli (Bellis, 2003). Processing of any type of sensory stimulus is reliant on general arousal state and attention. Therefore, the reduced attention skills in children may have inhibited their ability to attend to and process the UC MAST stimuli. Additionally, the fact that the adults were also tested in a comfortable, climate
controlled, sound-proof booth compared to the children who were tested in a warm, classroom, may have further contributed to the difference in UC MAST performance.

Therefore, even if basic sensory encoding is intact at all levels of the ascending auditory pathways, factors such neuromaturation and higher-order dysfunction or inadequate attention and cognitive ability will reduce the child’s ability to process the UC MAST stimuli, and ultimately comprehend spoken language causing a reduced performance on the UC MAST in comparison with adult participants.

**Hypothesis 4: There will be a strong correlation between the results of the adaptive computerised version of a low-pass filtered words test and the results of other test of filtered speech designed for APD diagnosis.**

The results from the current study indicate that there was no significant correlation between a child participant’s performance on the UC MAST and their performance on the Filtered Words subtest of the SCAN-C test for auditory processing disorders in children-revised (Keith, 2000c). Consequently, Hypothesis 4 was not supported.

As shown in the results, less variability was shown in the raw scores achieved both within and between the different age groups of the children on the SCAN-C test than on the UC MAST test. As a result, the correlation between the two tests was poor due the greater variability of UC MAST results compared to the reduced variability of the SCAN-C results.

The difficulty of the test depends on the degree of degradation of the stimuli and the extrinsic redundancy of the stimuli. The degree of degradation is dependent upon the cut-off frequency and the rejection rate of the filter. The amount of extrinsic redundancy is dependent on the test format.
The SCAN-C Test for Auditory Processing Disorders in Children-Revised (Keith, 2000c) is a revision of the original SCAN (Keith, 1986). Reduced variability in performance across age groups is usually more evident in closed-set response formats compared with the open-set response formats (Miller et al., 1951), as the closed-set tasks have greater extrinsic redundancy. Therefore, in terms of redundancy, greater variability would be expected on the open-set SCAN-C task. Consequently, the greater variation in the test scores on the UC MAST was most likely due to the more severe filter characteristics, namely the sharper rejection rate of the filter and the ability of the cut-off filter frequency to adapt to a participant’s performance. Like the UC MAST, the Filtered Words subtest consists of monosyllabic words that are low-pass filtered. However, in contrast to the UC MAST that adaptively filters closed-set stimuli with a filter slope of 230 dB per octave, the SCAN-C low-pass filters open-set stimuli at 1000 Hz with a filter slope of 32 dB per octave. The steeper slope of the filter on the UC MAST would let through less spectral information than the more gradual slope of the SCAN-C filter, thereby effectively narrowing the bandwidth of the filter.

The lack of variability and the relatively high mean scores obtained by the child participants on the SCAN-C Filtered Words test in this study suggest that the test may be too easy. In fact, Domitz and Schow (2000) concluded that further investigation was required regarding the sensitivity and specificity of SCAN compared with a battery of tests that are tailored to the ASHA (1996) recommendations. Further, (Anfinson et al.) found that there was no significant difference between the scores obtained by children with APD and without APD on the SCAN, and that the Filtered Words subtest had only 26% validity in terms of measuring auditory closure.
In summary, there was a poor correlation between the results for the child participants on the SCAN-C Filtered Words Subtest and the UC MAST. The poor correlation was most likely due to the difference the severity of the rejection rate implemented in each test. The more severe rejection rate in the UC MAST made the task more difficult than its SCAN-C counterpart. Consequently, there was greater variation in the threshold scores obtained on the UC MAST. This result suggests the sensitivity of the SCAN-C Filtered Words test may be limited, as previously suggested in the literature.

**Clinical implications**

Although the current study could not determine if the UC MAST could significantly identify children with and without APD, the results suggest that the clinical implications for a computerised, adaptive method of APD testing using the framework of the UC MAST are very promising.

To make the procedure simple to execute, it is implemented using software that can be easily installed on the computers currently used in most audiology clinics for the fitting and programming of hearing aids.

Additionally, the study demonstrated that the test is portable, and can be performed onsite in school environments if the test room is adequately prepared, comfortable, away from distractions and not prone to noise and temperature extremes. The test is fast and interactive, making it a more interesting option for children and reducing the impact of boredom and limited concentration span on the test results.

The UC MAST can also be easily adapted to use intensity, rather than frequency as the dependent variable. This has many implications for speech audiometry. Current speech audiometry practices are subject to administrator bias.
The four-alternative forced choice interface of the UC MAST removes subjective evaluation of the audiologist. The participant’s responses are automatically recorded and calculated by the computer running the UC MAST, preventing the chance that a response may be scored incorrectly and eliminating the need for calculations by the administrator.

The UC MAST format could also provide a good counselling tool for people with hearing loss by displaying the correct answer after each word selection. For example, by highlighting the correct word response, a person with a high frequency hearing loss and any accompanying family can clearly see how their hearing loss impacts on their ability to understand the clarity of words.

**Limitations**

The main limitation of the current study was obviously a lack of children with APD who could take part in the study. As mentioned in chapter five, potential candidates were sourced via the Group Special Education division of the Ministry of Education, via the Christchurch hospital waiting list, and through testing conducted at local primary school.

No suitable candidates were identified through either of the first two sources, which required a full APD test battery to be performed for each person. The length of time required to administer a full APD test battery and write the applicable reports was very time consuming and therefore, only a limited number of potential candidates could be tested in the permitted time frame.

Additionally, APD is often associated with other disorders, therefore not only was it difficult to source children with the disorder, but sourcing children who
presented with APD that were not restricted by other global disorders limited the potential candidates who could take part in the study.

A better strategy may have been to use children previously diagnosed with APD who have taken part in other research projects, even if it required travelling to areas outside of Christchurch.

The current study involved the testing of children from a decile six school. In hindsight, a lower decile schools may have yielded more chance of sourcing potential APD candidates.

Conducting the study with children in a school environment is also restrictive in terms of the time available for testing. Term times, school camps, assemblies, prayer-time, class tests, and class productions all made testing difficult in terms of access to the children. Additionally, the daily time frame for testing at the school was 9am until 3pm each day, however a double lunch break format at the school, as well as a morning and afternoon recess continually interrupted the available time window for testing to be completed.

Through better communication with the school, a timetable for the above activities should have been acquired so that the optimal time frame for conducting the testing could have been determined prior to beginning the project. Also, a school that implemented a single lunch break would have provided a more continuous test window throughout the day.

Additionally, as the testing was carried out in the school sick bay, interruptions were frequent and resulted in the room being required for other school activities during the test sessions. For security reasons, the equipment was required to be taken off site at the end of each test session. Therefore, the extensive time required for setting up and packing up the equipment used in the current study meant that at
least a spare half of a day was required for the test session to be worthwhile in terms of the number of children tested. To counter this problem, a school that provided a more secure test room that was not required for other purposes for the entire time frame of the study would have provided a more efficient environment that maximised the available time for testing.

A screening method was used to identify children likely to be more at risk of having an APD, however parental consent was not forthcoming for the majority of these children identified through this process. Although information packs were provided for each parent, a better strategy may have been to hold an information evening at the school to explain APD, the potential study and the benefits associated with taking part in the project.

**Directions for future research**

The primary purpose of the current study was to design the UC MAST to assess the auditory closure ability of children to determine if there was significant difference in the performance on the measure between children with and without an auditory processing disorder. Due to the difficulty in sourcing children with APD, this primary aim was not achieved.

Therefore, the most obvious direction for future research would be to source and test a viable number of children with APD using the UC MAST to determine if a significant difference existed between their UC MAST thresholds and those of age-matched children without the disorder.

As mentioned in chapter five, the current study aimed to compare children with and without APD and therefore, the right ear was always tested first to eliminate any bias from ear advantage bias. Further research could involve randomising the ear
order to determine if a true ear advantage is present in children, especially children at the lower end of the appropriate age bracket where such an advantage is presumably more obvious.

Additionally, continual modification of the programme was required throughout this study in an effort to counter the learning effect inherent in the measure and to determine the most efficient parameters for threshold determination. Future research could focus more attention on the structure of the adaptive staircase method implemented into the design of the programme to improve the efficiency and reliability of the UC MAST.

As mentioned in Chapter 3, the protocol developed by Mackie and Dermody (1986) was used as a starting point for the project and was based on a simple “one up/two down” or “one up/one down” adaptive speech threshold procedure derived by Levitt (1971), in which the level of filtering applied to the stimulus was adjusted by a fixed percentage after each correct or incorrect response.

The efficiency, accuracy and duration of the adaptive tracking procedure was dependent on a number of parameters, including step size, number of reversals and starting LPF value. The rational and significance for setting the values for these parameters was determined by systematic trial and error. However, research by Garcia-Perez (1998) suggests that if the ratio of the step size up to the step size down is constant at a specific value that changes with the “up/down rule”, then convergence on the percent correct target is less affected by the value of the above parameters. Garcia-Perez (1998) suggests that at least 20 reversals are required to reduce bias and improve precision of the procedure and that further improvement is also gained when the step size up is larger than half the spread of the psychometric function. For a list
of practical recommendations that could be used in future research involving the modification of the UC MAST, the reader is referred to Garcia-Perez (1998).

Another area for future research involving the current study could be aimed at keeping the child more focussed on the task through the introduction of a reward system throughout the test procedure. This could be in the form of an encouraging screen response after a correct answer is provided or based on an idea where by the child collects “keys” as the proceed through the task that “unlock” specific “screen rewards” at the end of the test. From the author’s experience with the current study, attention to task and the desire to perform the test well appeared to play a large part in the reliability of the threshold.

To take the above idea even further, an adaptive protocol could be implemented in an adventure video game in which a child must correctly identify stimuli to progress through the levels of the game. An example of a situation might include the choice of four doors to go through, with each door displaying a specific word from the NU-CHIPS list. If the child chooses the target word, then they progress to the next level, if their response is incorrect, then they go back a level.

Future research could also consist of using pictures to represent the stimuli rather than a display of the actual word as advocated by the results of previous studies (Keaster, 1947; Lerman et al., 1965; Ross & Lerman, 1970). Certainly, this would make the test more applicable to younger children. Research could focus on the ability of the UC MAST to identify APD in children at an earlier age so that management strategies and remediation activities can help the children achieve better classroom performance from an earlier age.

Finally, once the UC MAST has been further developed and refined, and provided a significant relationship is determined between performance of children
with and without APD, than normative data for the New Zealand population is inherent to the success of the measure and it’s clinical application.

**Conclusion**

The current study involved the design and development of a modified version of the traditional filtered words test – the UC MAST. The aim of the project was to improve the filtered words test by addressing issues that had previously limited the test in its ability to differentiate between children with and without APD. The modifications included the application of an adaptive procedure to replace the constant-level filter methods employed in previous versions of the test. Additionally, the UC MAST included a four alternative forced-choice interactive interface to eliminate administrator error associated with previous versions of the test.

As hypothesized, the UC MAST was reliable over repeated administrations for adult participants, albeit after some fine-tuning during the developmental stages of the project. The adult participants were more reliable than the child participants and therefore, there is scope for improvement in this area.

Unfortunately, due to the difficulty in sourcing children with APD who could take part in the study, the ability of the UC MAST to determine APD in children could not be determined, and the main hypothesis of the project could not be evaluated.

A comparison of the performance of adult participants with the performance of the child participants yielded results consistent with the literature in terms of maturation of the CANS and auditory processing ability. Adults performed the task significantly better than the children.
Finally, there was no correlation between the SCAN-C results and performance on the UC MAST. This was due to the greater variation in the UC MAST results between participants compared with the results obtained on the SCAN-C test, which tended to be skewed towards the ceiling of the test.

There is certainly potential in a test such as the UC MAST. The scope for future research is enormous and the combination of adaptive techniques and computer based interactive interfaces is very promising.
APPENDICES
Appendix I

Human Ethics Committee Approval

HEC Ref: 2006/32

26 June 2006

Mr Andrew McGaffin
Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Andrew

The Human Ethics Committee advises that your research proposal “Use of a monosyllabic adaptive filtered words test in the diagnosis of central auditory processing disorder.” has been considered and approved.

Yours sincerely

Dr Alison Loveridge
Chair, Human Ethics Committee
UC MAST instructions provided to each participant

“Shortly, I will place these headphones over your ears. Through the headphones, you will hear a lady’s voice. She will say a word, for example, cat. The word will sound a bit muffled like this.”

(A verbal example of the word was provided to the participant by the author who used their hand over their mouth to simulate the filtered word).

“After you hear the word, four words will appear on the monitor in front of you. Your task is to match the word you heard through the headphones with one of the words displayed on the monitor. *Use the mouse to click on the selection – like this.*”

(A demonstration of how to use the mouse to select a word on the screen was provided for the participant by the author).

“After you have selected a word, you will hear another word through the headphones. Again, you need to match this word with a word from the display. Sometimes the word will be very muffled, so muffled that it will be very difficult to understand. The word cannot be repeated, so if you’re not sure of the word, make a guess. The test will take about 5 minutes and will end automatically. When you are ready to begin, select the “start” button in the top right corner of the display. Do you have any questions?”

Note: *This line was replaced with the following lines for stage three of the project:

“To make your selection, simply point to the word on the display and touch the screen with your finger. You only need to touch the screen softly – like this.”*

(The author then provided a demonstration of using their finger to select a word on the touch screen).
School principal information letter

College of Science

Mr Andrew McGaffin,
Master of Audiology student
Department of Communication Disorders
Tel: +64 3 364 2987 ext. 7085, Fax: + 64 364 2760
Email: ajm280@student.canterbury.ac.nz

June 18, 2006

St. Teresa’s School
10 Puriri Street
Riccarton
Christchurch

Dear Sir or Madam:

I am a Master of Audiology student currently enrolled at the University of Canterbury, Christchurch, conducting a research study into the audiological diagnosis of auditory processing disorder (APD) in children.

APD is a term used to describe individuals with normal hearing who have auditory-based receptive communication or language learning problems. APD affects “what we do with what we hear”.

As part of this study, we will require participants of ages 9 and above, who have symptoms of APD (target participants), as well as those who do not (normal participants). The study involves using a computer-based programme to discriminate between the target and normal participants. The benefits of a successful study include the establishment of a more sensitive and efficient tool for identification of APD, and the application of computer based measurements to other aspects of audiological assessment.

Testing will typically involve one session of approximately 40 minutes to 60 minutes per participant. As each child (from both the normal and target groups) will be tested using the same test procedure, there will be no stigma attached to the length of time required of the child or the type of tests conducted.

We would like to commence testing of both normal participants and target participants as soon as possible. For ease of logistics, and if convenient, testing would preferably be carried out at the school, in a quiet room and preferably during class time, so as to minimise background noise.
We would greatly appreciate your approval to involve students at your school that fit the criteria for the participants required in this study. Provided your approval is obtained, questionnaires (sample is attached) will be delivered for completion by the teachers, which will help identify target and normal participants. Upon identification of participants, an information pack containing a letter of introduction, information sheet and consent form will be sent to the parents/ guardians of the target participants (sample attached).

All information obtained will be held in the strictest confidence within the Department of Communication Disorders at the University of Canterbury.

If you have any further questions about the research project, please do not hesitate to contact my supervisor, Dr. Greg O’Beirne, or myself at the University of Canterbury.

Thank you once again.

Sincerely,

Andrew McGaffin
Master of Audiology Student
Dept. of Communications Disorders
University of Canterbury
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Christchurch, New Zealand
Email: ajm280@student.canterbury.ac.nz
Phone: +64 3 960 2151
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Parent information letter

College of Science

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Project information sheet

PROJECT INFORMATION SHEET
FOR THE RESEARCH STUDY
USE OF A MONOSYLLABIC ADAPTIVE FILTERED WORDS TEST IN THE DIAGNOSIS OF CENTRAL AUDITORY PROCESSING DISORDER

PARENT INFORMATION

Your child is invited to participate in the research project; Use of a monosyllabic adaptive filtered words test in the diagnosis of central auditory processing disorder.

AIM OF PROJECT:

The aim of this project is to design a more efficient and sensitive test for the diagnosis of central auditory processing disorder in children using an adaptive testing procedure.

DURATION:

Your child’s involvement in this project will involve one session of approximately 40 – 60 minutes. The following is an outline of the tasks that may be required of your child:

PROCEDURE:

Otoscopy:
The child will have their ear canals examined using an otoscope (a specialised torch used for visual examination of the external ear and eardrum) to determine ear health.
Time required: 1 minute.

Audiometry:
A traditional hearing test will determine a child’s eligibility for the study. This involves monitoring a child’s response to stimuli presented at specific intensities.

Pure-tone audiometry: The child is seated in a quiet room, and tones are presented through headphones at variable intensities. The child is asked to press a button each time they hear the tone, which indicates that they heard the sound and have responded.

Time required: 10 – 20 minutes.

APD testing:
Each eligible child will undergo a test of central auditory processing using the commercially designed SCAN-C test battery and the adaptive filtered words test.
SCAN-C Test:
The SCAN-C test consists of four subtests administered to the child via headphones:

Subtest 1 Filtered Words: The child is asked to repeat stimulus words that sound muffled (low-pass filtered).

Subtest 2 Auditory Figure Ground: The child is asked to repeat stimulus words that were recorded in the presence of background noise.

Subtest 3 Competing Words: The child is asked to repeat stimulus words that are presented simultaneously to each ear.

Subtest 4 Competing Sentences: Pairs of sentences are presented to the both ears simultaneously. The child is asked to ignore the stimuli presented to one ear and direct attention to the other ear, and repeat the presented sentence.

Total Time required: 20 – 25 minutes.

Adaptive filtered words test:
Each child will be seated in front of a computer. Supra the child will wear aural headphones or insert earphones. Recordings of words of varying intelligibility will be presented verbally to the child through the phones. As each word is presented acoustically, four words will be presented visually on a computer display – of which one word will match the acoustically presented word. The task for the child is to choose a visually displayed word that they think matches the acoustically presented word, using a computer mouse to select the word on the computer display. This procedure will repeat itself until the child’s threshold is established. A practice session will precede the actual testing to help familiarise the child with the task.

Time required: 10 - 15 minutes.

WITHDRAWAL & CONFIDENTIALITY

Your child has the right to withdraw from the project at any time, including withdrawal of any information provided.

The results of the project may be published, but your child is assured of the complete confidentiality of data gathered in this investigation: the identity of your child will not be made public without their consent. To ensure anonymity and confidentiality, the information gathered will be assigned a code number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders.

The project is being carried out as a requirement for a Masters of Audiology by Andrew McGaffin, under the supervision of Doctor Greg O’Beirne, who can be contacted at the University of Canterbury on +64 3 364 2987 ext. 7085. We will be pleased to discuss any concerns you may have about participation in the project.
The project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

Andrew McGaffin
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Phone: +64 3 960 2151
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Phone: +64 3 364 2987 ext. 7085
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Parent Consent Form

College of Science

Mr Andrew McGaffin, Master of Audiology student
Department of Communication Disorders
Tel: +64 3 364 2987 ext. 7085, Fax: + 64 364 2760
Email: ajm280@student.canterbury.ac.nz

June 18, 2006

PARENTAL CONSENT FORM
FOR THE RESEARCH STUDY

USE OF A MONOSYLLABIC ADAPTIVE FILTERED WORDS TEST IN THE
DIAGNOSIS OF CENTRAL AUDITORY PROCESSING DISORDER

The purpose of this project is to design a more efficient and sensitive test for the diagnosis of central auditory processing disorder in children using an adaptive testing procedure. To determine the effectiveness of this new design, we need to conduct a series of audiological tests on a large number of children, and your participation in this study is greatly appreciated.

The audiological tests and requirements of the participant are outlined on the included information sheet for the above-named project. The tests are perfectly safe and in no way bring harm to the participant involved. Nonetheless, yourself or the participant involved, may end the test at any time and are free to discontinue participation in this project, including withdrawal of any information you or your child have supplied.

DECLARATION

I (the parent or legal guardian of the participant) have read and understood the description of the above-named project. I have also read and understood the requirements of the project as outlined in the information sheet for the above-named project. Any questions I have asked have been answered to my satisfaction. On this basis, I agree to allow my child to participate as a subject in this activity, realising that I may withdraw them at any time without prejudice.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator unless required to do so by law.

I agree that research data gathered for this study may be published, and I provide consent for this publication with the understanding that anonymity will be preserved, and my child’s name or other identifying information will not be used.

________________________________________  _________________________
Parent/Legal Guardian of Participant        Date
Child Consent Form

College of Science

Mr Andrew McGaffin, Master of Audiology student
Department of Communication Disorders
Tel: +64 3 364 2987 ext. 7085, Fax: + 64 364 2760
Email: ajm280@student.canterbury.ac.nz

April 28, 2006

CONSENT FORM
FOR THE RESEARCH STUDY
USE OF A MONOSYLLABIC ADAPTIVE FILTERED WORDS TEST
IN THE DIAGNOSIS OF CENTRAL AUDITORY PROCESSING
DISORDER

The purpose of this project is to design a more efficient and sensitive test for the diagnosis of central auditory processing disorder in children using an adaptive testing procedure. To determine the effectiveness of this new design, we need to conduct a series of audiological tests on a large number of subjects, and your participation in this study is greatly appreciated.

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I (the participant) have read and understood the description of the above-named project. I have also read and understood the requirements of the project as outlined in the information sheet for the above-named project. Any questions I have asked have been answered to my satisfaction. On this basis, I agree to participate as a subject in this activity, realising that I may withdraw at any time without prejudice.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator unless required to do so by law.

I agree that research data gathered for this study may be published, and I provide consent for this publication with the understanding that anonymity will be preserved, and my name or other identifying information will not be used.

_________________________________________  ______________________
Participant                                      Date
Teacher Information Letter

College of Science

Mr Andrew McGaffin, Master of Audiology student
Department of Communication Disorders
Tel: +64 3 364 2987 ext. 7085, Fax: + 64 364 2760
Email: ajm280@student.canterbury.ac.nz

June 18, 2006

St. Teresa’s School
10 Puriri Street
Riccarton
Christchurch

Dear Teacher:

I am a Master of Audiology student currently enrolled at the University of Canterbury, Christchurch, conducting a research study into the audiological diagnosis of central auditory processing disorder (APD) in children. APD is a term used to describe individuals with normal hearing who have auditory-based receptive communication or language learning problems. Basically, APD affects “what we do with what we hear”.

As part of this study, we will require participants who have symptoms of APD (target participants), as well as participants who show no symptoms of APD or any other learning disabilities (normal participants). The study involves using a computer-based programme to discriminate between subjects with and without an APD.

The benefits of a successful study include the establishment of a more sensitive and efficient tool for identification of APD, and the application of computer based measurements to other aspects of audiological assessment. For all participants, testing will typically involve one session of approximately 40 minutes to 60 minutes. Each child will receive the same test, regardless of whether they are identified as a possible target participant or normal participant.

We would greatly appreciate your assistance in identifying possible participants for this study. For the determination of participants, please find attached a questionnaire for your completion. The questionnaire is in three parts:
• Part A is an overview to screen for both target participants, as well as normal participants.

• Part B is a more in depth examination of the behaviour of each child identified in Part A as a possible target participant.

• Part C is for participants who will form the normal participant group.

An information pack containing a letter of introduction, an information sheet, and consent form will be sent to the parents/guardians of the students. All information obtained will be held in the strictest confidence within the Department of Communication Disorders at the University of Canterbury.

If you have any further questions about the research project, please do not hesitate to contact my supervisor, Dr. Greg O’Beirne, or myself at the University of Canterbury.

Thank you once again.

Sincerely,

Andrew McGaffin  
Master of Audiology Student  
Dept. of Communications Disorders  
University of Canterbury  
Private Bag 4800  
Christchurch, New Zealand  
Email: ajm280@student.canterbury.ac.nz  
Phone: +64 3 960 2151  
Mobile: +64 21 144 0665

Dr Greg O’Beirne  
Lecturer in Audiology  
Dept. of Communications Disorders  
University of Canterbury  
Private Bag 4800  
Christchurch, New Zealand  
Email: gregory.obeirne@canterbury.ac.nz  
Phone: +64 3 364 2987 ext. 7085  
Fax: +64 3 364 2760
Teacher Consent Form

Please read the following note before completing the questionnaire.

NOTE: You are invited to participate in the research project, ‘Use of a monosyllabic adaptive filtered words test in the diagnosis of central auditory processing disorder’ by completing the following questionnaire. The aim of the project is to design a more efficient and sensitive test for the diagnosis of central auditory processing disorder in children using an adaptive testing procedure.

The project is being carried out as a requirement for a Masters of Audiology by Andrew McGaffin, under the supervision of Dr. Greg O’Beirne who can be contacted at +64 3 364 2987 ext. 7085. He will be pleased to discuss any concerns you may have about participation in the project.

The questionnaire will be treated as anonymous, and you will not be identified as a participant without your consent.

You may withdraw your participation, including withdrawal of any information you have provided, until your questionnaire has been added to the others collected. Because it is anonymous, it cannot be retrieved after that.

By completing the questionnaire it will be understood that you have consented to participate in the project, and that you consent to publication of the results of the project with the understanding that anonymity will be preserved.
Teacher Questionnaire

FOR THE RESEARCH STUDY

USE OF A MONOSYLLABIC ADAPTIVE FILTERED WORDS TEST IN THE
DIAGNOSIS OF CENTRAL AUDITORY PROCESSING DISORDER

CHILDREN’S AUDITORY PROCESSING PERFORMANCE SCALE

PART A:

NAME OF PERSON COMPLETING QUESTIONNAIRE:

*Please circle either ‘yes” or “no” for the following questions:*

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do any of the children you teach:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have difficulty listening for appropriate length of time (poor concentration span)?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Have difficulty understanding abstract ideas?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have difficulty following verbal instructions?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Provide slow or delayed response to verbal stimuli?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Often need to have spoken information repeated?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Often misunderstand what is said?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Become easily distracted by auditory and visual stimuli?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Have difficulty listening in presence of background noise?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Have difficulty remembering things they have heard?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Have language deficits?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have academic difficulties, particularly with reading &amp; spelling?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Have difficulty comprehending words and their meaning?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rely on visual cues when attempting to communicate?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Has difficulty determining where sounds are coming from?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Have history of middle ear infections/ fluctuating hearing loss?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Have lowered self-esteem?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you have circled ‘yes’ for *any* of the above questions, then please complete a separate Part B of the questionnaire for *each* individual student (provided the student is 9 years or above & English is their native language). Depending on their results in Part B, these students may potentially be part of the target participant group.

Of the remaining students who you teach, (those who would record a ‘no’ answer for *all* of the above questions) if their native language is English, then please list their names in Part C of the questionnaire – these students may potentially be part of the normal participant group.
Part B:

Date: ________  Child’s Name: ________  Age: ___ yrs ___ months

Please photocopy this part of the questionnaire as required, so that a separate Part B is recorded for each student who would record a ‘yes’ answer for any question in Part A. Please take your time marking each child’s score – perhaps even monitoring one or two children each day.

Answer all questions by comparing this child to other children of similar age and background. Do not answer the question based only on the difficulty of the listening condition. For example, all 8-year-old children, to a certain extent, may not hear and understand when listening in a noisy room. That is, this would be a difficult listening condition for all children. However, some children may have more difficulty in this listening condition than others. You must judge whether or not this child has MORE difficulty than other children in each listening condition cited. Please make your judgement using the following response choices: (CIRCLE a number for each item.)

**RESPONSE CHOICES**

<table>
<thead>
<tr>
<th>Difficulty Level</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>LESS DIFFICULTY</td>
<td>+1</td>
</tr>
<tr>
<td>SAME AMOUNT OF DIFFICULTY</td>
<td>0</td>
</tr>
<tr>
<td>SLIGHTLY MORE DIFFICULTY</td>
<td>-1</td>
</tr>
<tr>
<td>MORE DIFFICULTY</td>
<td>-2</td>
</tr>
<tr>
<td>CONSIDERABLY MORE DIFFICULTY</td>
<td>-3</td>
</tr>
<tr>
<td>SIGNIFICANTLY MORE DIFFICULTY</td>
<td>-4</td>
</tr>
<tr>
<td>CANNOT FUNCTION AT ALL</td>
<td>-5</td>
</tr>
</tbody>
</table>

**Listening Condition = NOISE:**

If listening in a room where there is background noise such as a TV set, music, others talking, children playing, etc., this child has difficulty hearing and understanding (compared with other children of similar age and background).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>When paying attention</td>
<td>+1</td>
</tr>
<tr>
<td>When being asked a question</td>
<td>+1</td>
</tr>
<tr>
<td>When being given simple instructions</td>
<td>+1</td>
</tr>
<tr>
<td>When being given complicated, multiple, instructions</td>
<td>+1</td>
</tr>
<tr>
<td>When not paying attention</td>
<td>+1</td>
</tr>
<tr>
<td>When involved with other activities, i.e., colouring etc</td>
<td>+1</td>
</tr>
<tr>
<td>When listening with a group of children</td>
<td>+1</td>
</tr>
</tbody>
</table>

**Listening Condition = QUIET:**

If listening in a room (other members may be present, but are being quiet), this child has difficulty hearing and understanding (compared with other children of similar age and background).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>When paying attention</td>
<td>+1</td>
</tr>
<tr>
<td>When being asked a question</td>
<td>+1</td>
</tr>
<tr>
<td>When being given simple instructions</td>
<td>+1</td>
</tr>
<tr>
<td>When being given complicated, multiple, instructions</td>
<td>+1</td>
</tr>
<tr>
<td>When not paying attention</td>
<td>+1</td>
</tr>
<tr>
<td>When involved with other activities, i.e., colouring etc</td>
<td>+1</td>
</tr>
<tr>
<td>When listening with a group of children</td>
<td>+1</td>
</tr>
</tbody>
</table>

**Listening Condition = IDEAL:**

If listening in a quiet room, no distractions, face-to-face, and with good eye contact, this child has difficulty hearing and understanding (compared with other children of similar age and background).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>When being asked a question</td>
<td>+1</td>
</tr>
<tr>
<td>When being given simple instructions</td>
<td>+1</td>
</tr>
<tr>
<td>When being given complicated, multiple, instructions</td>
<td>+1</td>
</tr>
</tbody>
</table>
PART B (continued)

Child's Name:

<table>
<thead>
<tr>
<th><strong>Listening Condition = MULTIPLE INPUTS:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>When in addition to listening, there is also some other form of input (i.e., visual, tactile, etc.), this child has difficulty hearing and understanding (compared with other children of similar age and background).</td>
<td></td>
</tr>
<tr>
<td>When listening and watching the speaker's face</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When listening and reading material that is also being read out loud by another</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When listening and watching someone provide an illustration such as a model, drawing, information on the chalkboard, etc.</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Listening Condition = AUDITORY MEMORY/ SEQUENCING:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>If required to recall spoken information, this child has difficulty (compared with other children of similar age and background).</td>
<td></td>
</tr>
<tr>
<td>Immediately recalling information such as a word, word spelling, numbers, etc.</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>Immediately recalling simple instructions</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>Immediately recalling multiple instructions</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>Not only recalling information, but also the order or sequence of the information</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When delayed recollection (1 hour or more) of words, word spelling, numbers, etc. is required</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When delayed recollection (1 hour or more) of simple instructions is required</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When delayed recollection (1 hour or more) of multiple instructions is required</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Listening Condition = AUDITORY ATTENTION SPAN:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>If extended periods of listening are required, this child has difficulty paying attention that is being attentive to what is being said (compared with other children of similar age and background).</td>
<td></td>
</tr>
<tr>
<td>When the listening time is less than 5 minutes.</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When the listening time is 5 to 10 minutes.</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When the listening time is over 10 minutes.</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When the listening is in a noisy room</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When listening first thing in the morning</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When listening near the end of the day</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
<tr>
<td>When listening in a room where there are also visual distractions</td>
<td>+1 0 -1 -2 -3 -4 -5</td>
</tr>
</tbody>
</table>
**Part C:**

Date:

**NAMES OF CHILDREN WHO:**
- ARE AGED 9 OR ABOVE
- DO NOT EXHIBIT APD SYMPTOMS
- DO NOT EXHIBIT ANY OTHER LEARNING DISABILITIES &
- SPEAK ENGLISH AS A NATIVE LANGUAGE


Thank you for your time and co-operation. Please return your questionnaires to the school office for collection.

Regards,

Andrew McGaffin
Appendix II

Table II -1: Individual adult participant results for the UC MAST Pilot Study.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Right ear</th>
<th>Left ear</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial #1 (Hz)</td>
<td>Trial #2 (Hz)</td>
</tr>
<tr>
<td>1</td>
<td>633</td>
<td>692</td>
</tr>
<tr>
<td>2</td>
<td>716</td>
<td>762</td>
</tr>
<tr>
<td>3</td>
<td>930</td>
<td>715</td>
</tr>
<tr>
<td>4</td>
<td>632</td>
<td>584</td>
</tr>
<tr>
<td>5</td>
<td>764</td>
<td>822</td>
</tr>
<tr>
<td>6</td>
<td>790</td>
<td>765</td>
</tr>
<tr>
<td>7</td>
<td>918</td>
<td>917</td>
</tr>
<tr>
<td>8</td>
<td>1152</td>
<td>1139</td>
</tr>
<tr>
<td>9</td>
<td>525</td>
<td>621</td>
</tr>
<tr>
<td>10</td>
<td>875</td>
<td>617</td>
</tr>
<tr>
<td>n</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mean (Hz)</td>
<td>793</td>
<td>763</td>
</tr>
<tr>
<td>Std Dev (Hz)</td>
<td>183</td>
<td>166</td>
</tr>
<tr>
<td>Range (Hz)</td>
<td>525 to 1152</td>
<td>584 to 1139</td>
</tr>
</tbody>
</table>
### Table II-2: Individual adult participant threshold scores for the 71% UC MAST

<table>
<thead>
<tr>
<th>Participant</th>
<th>Right ear</th>
<th>Left ear</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial #1 (Hz)</td>
<td>Trial #2 (Hz)</td>
</tr>
<tr>
<td>1</td>
<td>492</td>
<td>486</td>
</tr>
<tr>
<td>2</td>
<td>705</td>
<td>504</td>
</tr>
<tr>
<td>3</td>
<td>632</td>
<td>584</td>
</tr>
<tr>
<td>4</td>
<td>531</td>
<td>464</td>
</tr>
<tr>
<td>5</td>
<td>672</td>
<td>557</td>
</tr>
<tr>
<td>6</td>
<td>708</td>
<td>580</td>
</tr>
<tr>
<td>7</td>
<td>534</td>
<td>547</td>
</tr>
<tr>
<td>8</td>
<td>1034</td>
<td>807</td>
</tr>
<tr>
<td>9</td>
<td>500</td>
<td>685</td>
</tr>
<tr>
<td>10</td>
<td>627</td>
<td>650</td>
</tr>
<tr>
<td>11</td>
<td>987</td>
<td>938</td>
</tr>
<tr>
<td>12</td>
<td>562</td>
<td>544</td>
</tr>
<tr>
<td>13</td>
<td>1042</td>
<td>890</td>
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<tr>
<td>14</td>
<td>1104</td>
<td>906</td>
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<tr>
<td>15</td>
<td>625</td>
<td>615</td>
</tr>
<tr>
<td>16</td>
<td>1018</td>
<td>1022</td>
</tr>
<tr>
<td>17</td>
<td>818</td>
<td>786</td>
</tr>
<tr>
<td>18</td>
<td>501</td>
<td>697</td>
</tr>
<tr>
<td>19</td>
<td>530</td>
<td>509</td>
</tr>
<tr>
<td>20</td>
<td>707</td>
<td>690</td>
</tr>
<tr>
<td>21</td>
<td>738</td>
<td>796</td>
</tr>
<tr>
<td>22</td>
<td>443</td>
<td>397</td>
</tr>
<tr>
<td>23</td>
<td>553</td>
<td>424</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>23</th>
<th>23</th>
<th>23</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (Hz)</td>
<td>698</td>
<td>655</td>
<td>670</td>
<td>669</td>
<td></td>
</tr>
<tr>
<td>Std Dev (Hz)</td>
<td>205</td>
<td>175</td>
<td>175</td>
<td>172</td>
<td></td>
</tr>
<tr>
<td>Range (Hz)</td>
<td>1104 to 443</td>
<td>1022 to 397</td>
<td>1044 to 400</td>
<td>1025 to 441</td>
<td></td>
</tr>
</tbody>
</table>
Table II -3: Individual child participant threshold scores for the 71% UC MAST

<table>
<thead>
<tr>
<th>Participant</th>
<th>Right ear</th>
<th>Left ear</th>
<th>Right ear</th>
<th>Left ear</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial #1 (Hz)</td>
<td>Trial #2 (Hz)</td>
<td>Trial #1 (Hz)</td>
<td>Trial #2 (Hz)</td>
</tr>
<tr>
<td>1</td>
<td>924</td>
<td>863</td>
<td>572</td>
<td>656</td>
</tr>
<tr>
<td>2</td>
<td>966</td>
<td>870</td>
<td>853</td>
<td>870</td>
</tr>
<tr>
<td>3</td>
<td>1034</td>
<td>939</td>
<td>1025</td>
<td>593</td>
</tr>
<tr>
<td>4</td>
<td>1046</td>
<td>1107</td>
<td>1048</td>
<td>968</td>
</tr>
<tr>
<td>5</td>
<td>1860</td>
<td>1013</td>
<td>1101</td>
<td>992</td>
</tr>
<tr>
<td>6</td>
<td>882</td>
<td>922</td>
<td>1125</td>
<td>910</td>
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<tr>
<td>7</td>
<td>1273</td>
<td>1242</td>
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<td>1378</td>
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<td>8</td>
<td>1381</td>
<td>717</td>
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<tr>
<td>9</td>
<td>1422</td>
<td>720</td>
<td>760</td>
<td>641</td>
</tr>
<tr>
<td>10</td>
<td>1282</td>
<td>995</td>
<td>1111</td>
<td>1146</td>
</tr>
<tr>
<td>11</td>
<td>1479</td>
<td>1538</td>
<td>974</td>
<td>1075</td>
</tr>
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<td>12</td>
<td>851</td>
<td>834</td>
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<td>666</td>
</tr>
<tr>
<td>18</td>
<td>743</td>
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*Note: DNT = Did Not Test*
Table II -4: Individual adult participant threshold scores for the 50% UC MAST

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Note: DNT = Did Not Test
Table II -6: Individual adult and child participant monaural threshold scores for the 71% UC MAST

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### Table II -7: Individual child participant SCAN-C test results

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References


