The Development of the Arabic Lexical Neighbourhood Test

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Declaration

I, Nada Abdulkader M Alsari, confirm that the work presented in this thesis is my own.

Where information has been derived from other sources, I confirm that this has been indicated in the thesis. Portions of this thesis have been published in conference proceedings.

Dedication

I dedicate this work to my loving mother and father, Asma and Abdulkader, my brothers Mohammed and Abdullah and my sister Noran whose continuous support and encouragement has allowed me to accomplish my dreams in every aspect of my life. Also, I dedicate this work to my loving and devoted husband Ahmed whose unconditional love and commitment gives me the strength to follow my ambitions in life. Finally, I dedicate this thesis to our lovely daughter Dana who passed away from Pompe disease at the beginning of my PhD. course, our beautiful daughter Asma who continues to battle this fatal disease, and our wonderful healthy daughter Lana who constantly brings joy into our lives every single day…

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Abstract:

Speech perception is a primary outcome measure in children using cochlear implants (CI). Saudi Arabia has a high prevalence of hearing loss, however, there are no appropriate measures to assess communication skills in these children post cochlear implantation. This thesis describes the development and application of an Arabic version of the Lexical Neighbourhood Test (Kirk, Pisoni, & Osberger, 1995) for children using CIs in Saudi Arabia. Study 1 consisted of language sampling and developing the Arabic Lexical Neighbourhood Test (ALNT) word lists. Study 2 examined performance of normal hearing (NH) children on the ALNT in two conditions: in noise and in quiet via vocoded speech simulating a CI. Study 3 investigated the performance of CI children on the ALNT in quiet over time, with 3 measurements made over a period of approximately 18 months. In general, results indicated that the ALNT was a reliable speech perception test. Both CI and NH children consistently scored higher on the easy words than the hard words which is consistent with the effects of the lexical factors of word frequency and neighbourhood density on speech perception. Another factor that was also explored was whether repeated administration of test items affected performance. In NH children, when time intervals between first and second administration was 2-4 weeks, repetition effects were evident. In CI children however, when the test intervals between repeated administrations was 6-9 months apart, repetition effects were not evident. This demonstrates that the ALNT can be used repeatedly without affecting speech perception performance. Finally, the sensitivity of the ALNT to change in performance over time was compared to a nonsense CV test that was also administered to CI children over three sessions. The CV test was found to be more sensitive to change over time than the ALNT.

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1 Chapter one: Introduction

Hearing impairment is one of the most prevalent disorders in Saudi Arabia. Prevalence rates of hearing loss have been reported to be very high (7.7 %) when compared to other countries across the globe (Mathers, Smith, & Concha, 2000) and incidence rates appear to be increasing over time (Al-Abduljawad & Zakzouk, 2003). This high incidence is largely associated with congenital (Habib & Abdelgaffar, 2005) and childhood onset loss (Al-Rowaily, AlFayez, AlJomiey, AlBadr, & Abolfotouh, 2012), and has been attributed to the high consanguinity rate in marriages among the Saudi Population (AlMazrou, Farid, & Khan, 1995; Jamal, Daghistani, & Zakzouk, 2002; Zakzouk, 2002).

Cochlear implants (CI) have become more available recently in Saudi Arabia and as a result of the high prevalence of childhood hearing loss, the number of child candidates for CIs is considerable. For example in 2002, the percentage of children diagnosed with severe to profound hearing loss was 0.7% (Al-Shaikh & Zakzouk, 2003; Al-Shaikh, Zakzouk, Metwalli, & Dasugi, 2002) . With the increased use of implants, there is a growing need for appropriate measures of post-implantation progress in Saudi children. In the assessment of speech perception, tests that are language and age-appropriate are required, not only for assessment but also to guide aural rehabilitation (Mendel, 2008). Currently, speech perception assessments in Saudi Arabia are conducted using either Arabic translations of English tests or Arabic tests that have been developed in Arabian countries other than Saudi Arabia (Nasser, Al-Sari, & Al-Malki). Tests translated into Arabic from English are unlikely to be well-adapted to the language of Saudi children. Similarly, tests developed in other Arabic dialects are likely to include words that are not familiar to Saudi Arabian children. More robust methods are thus required, which use appropriate test materials and which have been shown to give reliable information.

The Arabic language is well known for its diverse dialects. Even within Saudi Arabia a wide range of spoken dialects has been documented. There are five basic dialects; Najdi which is spoken in the central region, Hijazi which is spoken in the western region, Gulf Arabic which is spoken in the eastern region, and the Southern and Northern regional dialects (Alkanhal, Alghamdi, Alotaibi, & Alinazi, 2008; Prochazka, 1988). This dialectal variety poses difficulties in constructing tests that are applicable across the whole country. One solution might be the use of Modern Standard Arabic, which is not subject to dialect variation (Ashoor & Prochazka, 1985). However, Modern Standard Arabic is seldom used in daily conversation, so few words would be universally familiar to children. In order to avoid this dilemma, the current study addresses the development of a test in one dialect, the central region Najdi dialect. This region includes Riyadh, and is the region with the highest prevalence of bilateral sensorineural hearing loss within Saudi Arabia (Al-Abduljawad & Zakzouk, 2003; Bafaqeeh, Zakzouk, Almuhaimeid, & Essa, 1994; ElSayed & Zakzouk, 1996).

The overall aim of the current study was twofold. First, to develop an Arabic test founded on the same concept as the Lexical Neighbourhood Test (LNT) as developed in English by Kirk et al. (1995). This approach offers a theoretically grounded rationale for the selection of test materials, and has already been taken as the basis for assessments of word recognition in children with CIs in several other languages, including Mandarin and Cantonese Chinese (Liu et al., 2011; Yuen et al., 2008). Both of these languages differ greatly in their phonology from English, as does Arabic. For the LNT, test words are drawn from a language sample collected from children representing the population to be tested. The selection of test words takes account of the number of words in the sample that are phonetically similar to the test word, as measured by neighbourhood density, and the frequency of occurrence of the word within the sample. Thus, test materials reflect the phonological properties of the test language in a way that is unlikely to be achieved by the translation of lexical items from one language to another, since the objects, actions and concepts that common words refer to are likely to vary between languages and cultures. The approach also allows control over effects of children's limited vocabulary (Kirk, Diefendorf, Pisoni, & Robbins, 1997), since test items are selected from an age-appropriate vocabulary.

An essential part of the primary aim included investigating the reliability of this newly developed test by conducting a test-retest reliability experiment on children with normal hearing (NH) in noise as well as investigating the clinical feasibility of the test for assessing word recognition in children using CIs.

Secondly, the thesis addresses the validity in languages other than English of the theoretical model that underpins the design of the LNT, the Neighbourhood activation model (Luce & Pisoni, 1998). Hence, the work investigates the lexical effects of word frequency and neighbourhood density on word recognition by Arabic children, including those with NH and children using CIs.

2 Chapter two: Language Sampling and the development of the Arabic Lexical Neighbourhood Test items

2.1 Introduction

Assessment of speech perception in hearing impaired children is important for the following reasons: First, results aid in determining whether a child is benefiting from a hearing aid or should be considered for a cochlear implant (CI). Second, this assessment is essential for comparing differences between sensory devices and/or processing algorithms. Third, follow-up assessments help monitor progress over time. Finally, speech perception data in combination with speech and language outcomes are important for establishing guidelines for re/habilitation (Eisenberg, Johnson, & Martinez, 2005).

Speech perception tests cover a wide range of skills, from the ability to perceive single phonemes to the ability to perceive sentences. Criteria for developing speech perception tests differ depending on the type of test to be developed. This thesis describes a word recognition test, which is one of the most common types of tests used with young hearing-impaired children. In developing such a test, amongst the criteria that should be considered when developing a word recognition test are word familiarity, test format (closed set vs. open set) and presentation format (auditory only, auditory and visual, in quiet vs. in noise). Other factors that may influence speech perception performance and should also be considered include subject's age and language level (Bergeson, Pisoni, & Davis, 2005; Clopper, Pisoni, & Tierney, 2006).

The country of Saudi Arabia is one of the countries with the highest prevalence of hearing loss around the world (Mathers et al., 2000). And given the increased number of children receiving hearing aids and CIs, there is a need for assessing speech perception in these children. The lack of such tests in the Arabic language, specifically for the Saudi population, was what motivated this research project. Further, the test developed here is theoretically driven and is founded on the same concept as The Lexical Neighbourhood Test developed by Kirk et al. (1995) which has already been used to assess word recognition in English-speaking children with CIs.

Thus, the purpose of this study was to develop an Arabic Lexical Neighbourhood Test (ALNT) to assess speech perception outcome at the word level in Arabic speaking children with CIs.

2.1.1 The Neighbourhood activation model

The Neighbourhood Activation Model (NAM: Luce and Pisoni, 1998) is an influential model of auditory word recognition that develops the notion of the mental lexicon as a multidimensional space previously proposed by Treisman (1978). NAM assumes that words are organized in the mental lexicon according to 'similarity neighbourhoods' where neighbours are words that can be formed by the addition, deletion, or substitution of one phoneme (Greenberg & Jenkins, 1964; Landauer & Streeter, 1973). The NAM also takes account of word frequency whereby common words are more easily identified than uncommon words even when speech intelligibility is low (Savin, 1963). However, this latter factor is considered supplementary rather than fundamental in the NAM.

When a stimulus is presented to a listener, the model assumes that this activates a series of acoustic-phonetic pattern representations within the lexicon which in turn activate a number of 'word decision units'. These decision units have two functions: monitoring activation levels of the acoustic-phonetic pattern representations and allowing an influence from higher level lexical information such as word frequency and other contextual factors that affect the listener's expectation of a word being heard. Thus, word decision units can be seen as the boundary between acoustic-phonetic information and higher lexical information: the acoustic-phonetic pattern representations activate the decision unit, while word frequency and context can introduce bias by further adjusting the levels of activation in the word decision units. Activation levels are assumed to develop over time with additional processing of input and higher-level information until one decision unit becomes more activated than its competitors, at which time word recognition occurs. An important prediction of this model is the effect of neighbourhood density, whereby words that have a large number of acoustically-similar neighbours will be difficult to recognize, while words with few similar neighbours will show high recognition accuracy (Luce & Pisoni, 1998).

2.1.2 The Lexical Neighbourhood Test

Several neighbourhood based speech perception tests have been developed in English. One test which is of particular interest to the current study is the Lexical Neighbourhood Test (LNT).

On the basis of the perspectives on word recognition and lexical access provided by the NAM, Kirk et al. (1995) developed the LNT and the Multisyllabic Lexical Neighbourhood Test (MLNT). The main rationale was to develop a speech perception test for children with hearing impairment and children using CIs which includes only words that are familiar to such children given their limited vocabulary. Another aim was to try to understand the underlying perceptual process applied by these children to achieve lexical access.

Test items for the LNT were generated from speech elicited from typically developing English speaking children between the ages of 3 and 5 years on the assumption that their vocabulary would be similar to that of somewhat older children with CIs. This data, in the form of phonetic transcriptions, was derived from an extensive language database within the Child Language Data Exchange System (CHILDES) (MacWhinney, 1996).

The LNT test consists of two lists, each containing 50 monosyllabic words. Within each list, 50% of the words are considered lexically hard while the other 50% are lexically easy. The hard and easy words were defined according to word frequency and neighbourhood density. Word frequency is the number of times a word occurs in a particular language inventory. Neighbourhood density is here defined as the number of words that differ from the test word by the substitution, omission or addition of one phoneme. Of the 20,000 words found on the CHILDES database for 3 – 5 year olds, neighbourhood density ranged from 1-19 and word frequency ranged from 1-519. The median for both word frequency and neighbourhood density was 4. Easy words were defined as being above the median for word frequency and below the median for neighbourhood density while hard words were defined as being below the median for word frequency and above the median for neighbourhood density.

The MLNT was constructed using the same method as the LNT. It also consisted of an easy and a hard word list however the words included in these lists were 2-3 syllable words. Word frequency ranged from 1 to100 with a median of 2 while neighbourhood density ranged from 2 to 7 with a median of zero. Easy words were those that had word frequencies greater than 2 and neighbourhood densities of zero whereas hard words were those with word frequencies of less than 2 and neighbourhood densities greater than zero.

The current study aimed at developing an Arabic version of the English LNT. Because of the huge differences between Arabic and English language, an overview of the structure of Arabic language will be presented prior to the construction of the Arabic Lexical Neighbourhood Test (ALNT).

2.1.3 Origin of Arabic language

Arabic is a member of the semitic language group which constitutes a branch of the Afroasiatic language family (Hetzron, 1992). Today, it is considered one of the most widely spoken semitic languages around the globe and according to recent estimates, there are approximately 237 million native speakers of Arabic (Lewis, Simons, & Fennig, 2014). This number exceeds 450 million if non-native Arabic speakers are included (Lewis et al., 2014).

The Arabic language originated in the Arabian peninsula (Ernst, 2013; Watson, 2002) which is now called Saudi Arabia. The rise of Islam at the end of the sixth century in the Arabian peninsula led to the rapid spread of Islam throughout the middle east which had extended within a century to North Africa. In the following centuries it reached Spain in the west and India and China in the east (Gibb, 1978). The expansion of Islam was a linguistic conquest as well as a religious conquest and in year 691 Arabic became the official language of governance in the early Islamic empire (Ernst, 2013). Within a few centuries, Arabic also became the formal and informal language of all Islamic countries across the Middle East (Versteegh & Versteegh, 1997), and its literature is the source of a huge number of literary works covering all fields of culture, religion, history, and science (Ernst, 2013).

The Arabic Language spoken at present is mainly derived from the old dialects in Central and North Arabia. These dialects can be divided into three main groups: Hijaz, Najd, and the languages of the tribes in adjacent areas. The Hijazi dialect is considered the purest of all groups while the languages of the tribes are considered to be greatly affected by the other semitic and non-semitic languages (Holes, 1995). Arabic is currently the official language of 20 countries in western Asia and North Africa. These countries are: Algeria, Bahrain, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Qatar, Saudi Arabia, Somalia, Sudan, Syria, the United Arab Emirates, Tunisia, and Yemen. Arabic is also spoken by Palestinians, some speakers in south west of Iran, southern Turkey, and Chad as well as the Arab communities in Europe and America (Watson, 2002).

2.1.4 The emergence of Diglossia

In the eighth century, literary Arabic began to reach a standard form via the development of grammatical forms (Fischer, 1997). This can be labelled as standard Arabic. Colloquial Arabic and its dialects on the other hand, had greatly increased during this period. Thus, the Arabic language has one standard (formal) form and a huge number of regional and social dialects (informal) and is consequently considered a diglossic language. It is essential to note that people in the Arab world are not brought up to talk in standard Arabic, and their mother tongue would be the Arabic dialect of their home region. Standard Arabic however, is only learnt at school and at home for educational purposes and is restricted to formal spoken or written circumstances. Today, standard Arabic differs greatly from colloquial Arabic in terms of its phonology, morphology, syntax, and lexicon (Watson, 2002).

Arabic dialects form a continuous spectrum stretching from east to west where dialects at both extremes are equally unintelligible (Watson, 2002). This diglossia makes the development of speech and language tests in Arabic somewhat problematic, especially if the aim is to develop an Arabic test to suit all Arabic speakers. In other words, developing a test in standard Arabic would be insufficient as this form of Arabic language is only used in formal occasions and some people, particularly those who are undereducated, may not have been exposed to this form of Arabic. On the other hand, if one was to develop a test containing vocabulary from colloquial Arabic, it would be impossible to create a test that would be comprehensible across all Arabic dialects.

2.1.5 Characteristics of Arabic versus English Language

Arabic and English language differ in many aspects. For example, Arabic is written from right to left (Hasanuzzaman, 2013), is cursive, has no upper and lower case letters, and letters change in shape according to their position (initial, middle, or final) in a word (Holes, 1995).

In contrast, English is written from left to right, is written in either cursive form or in block letters and has upper and lower case letters. There are 28 alphabetical letters in the Arabic language, compared to the 26 English letters, all of which are consonants except for one (alif) which carries the (hamza). The (hamza) is also consonantal and may appear on its own but is not considered a separate letter. Arabic plural forms include singular, dual and plural whereas English only has singular and plural forms. Also, Arabic differentiates masculine from feminine genders in pronouns, verbs, adjectives and nouns as opposed to English. Regarding verb tenses, past tenses are indicated by a suffix while present tenses are indicated by a prefix (Hasanuzzaman, 2013). For example, for the word meaning 'eat' /ækæl/; the present form for the masculine gender would be /jækʊl/ and for the female gender would be /tækʊl/ whereas the past form would be /ækæl/ for the male gender and /ækælæt/ for the female gender. Finally, feminine nouns receive masculine numerals and masculine nouns receive feminine numerals.

2.1.6 Phonology

Arabic is mainly a consonantal language with a limited vocalic system. There are three basic vowels (/a/, /i/, /u/), each occurring in a short and long form. Vowels appear freely in medial and final word positions but must be preceded by a glottal stop (hamza) if they are to occur initially in words. Vowels also demonstrate "phonetic harmony" according to whether or not they are adjacent to emphatic sounds. That is, if vowels are adjacent to emphatic sounds they become retracted and/ or centralized whereas if they are adjacent to non-emphatic sounds they become more peripheral (Kopczynski & Meliani, 1993). Arabic is also known for a rich inventory of guttural consonants which include glottals (/ʔ/and/h/), pharyngeals (/ʕ/and /ħ/), uvular fricatives (/χ/ and /ɣ/). These sounds are produced at the back of the oral cavity. The Arabic phonemic inventory also includes emphatic consonants (/ṭ/, /ḍ/, /ẓ/, and /ṣ/) which are velarized and produced by raising the back of the tongue towards the soft palate. Except for glottals, these emphatic and guttural consonants are not present in the English phonemic inventory. On the other hand, the following English consonants do not occur in the Arabic phonemic inventory /p/, /v/, /ɹ/, and /ŋ/. The following consonants are shared by both Arabic and English: /b/, /t/, /d/, /k/, /g/, /f/, /Ɵ/, /ð/, /s/, /z/, /h/, /m/, /n/, /l/, /r/, /w/ and /j/.

2.1.7. Morphology

A main feature in the Arabic language is its root and pattern morphology. The root is a series or sequence of two, three, or four consonants which are mapped onto certain patterns for the derivation of meaningful words (Ryding, 2005; Watson, 2002). The consonants within a root however must be in a specific order. Patterns contain one or more vowels (and sometimes consonants) as well as slots in which the consonants of the root fit. This can be observed in Table 2.1. Both roots and patterns are considered bound morphemes as neither of them can stand alone. Each root can be thought of as signifying a semantic field because all the words that are derived from a certain root are related to the semantic field denoted by this root (Ryding, 2005) e.g. /r-s-m/: relates to drawing, /ʃ-r-b/, relates to drinking. It is estimated that there are approximately 10000 roots in Arabic language (Gridach & Chenfour, 2011). Patterns however, can be regarded as templates on to which roots are drawn. The process of pattern formation involves three components: six vowels (short and long forms of /a/, /i/ and /u/), seven consonants (/t/, /m/, /n/, /s/, /w/, /j/ and /ʕ/), and the process of gemination (doubling of consonants) (Ryding, 2005). An example of the combination of a root and several patterns is displayed in Table 2.1 which shows the various words that can be derived from the root /k-t-b/. To illustrate how words are derived from roots, the slots or dashes in the following root /-k-t-b-/ are usually replaced by vowels or consonants to form different words depending on the type of pattern that is intended for use. For example, to derive the word meaning ‘book’, the pattern structure CVCVC will be used by inserting the vowels /ɪ/ and /æː/ in the middle slots i.e. /kɪtæːb/.

Table 2.1: Range of different words that can be derived from the root /k-t-b/:

Word	Structure	Meaning
/kætæb/	CVCVC	He wrote
/kætæbæt/	CVCVCVC	She wrote
/kɪtæːb/	CVCVC	Book
/kæːtɪb/	CVCVC	Male writer
/mæktæbæh/	CVCCVCVC	Book store
/mæktub/	CVCCVC	Written
/æktʊb/	VCCVC	I write
/ʊktʊb/	VCCVC	Write!
/mæktæb/	CVCCVC	Office/ desk
/næktʊb/	CVCCVC	We write
/mækæːtɪb/	CVCVCVC	Offices/ desks
/mæktæbæːt/	CVCCVCVC	Book stores
/kʊttæːb/	CVCCVC	Writers
/kɪtæːbæh/	CVCVCVC	Writing
/kætæbnæ/	CVCVCCV	We wrote
/jæktʊb/	CVCCVC	He writes
/tæktʊb/	CVCCVC	She writes
/kʊtʊb/	CVCVC	Books
/kæːtɪbæh/	CVCVCVC	Female writer

It is essential to consider the word structure of Arabic language as this has implications for the process of choosing words for any speech and language test. Arabic words rarely occur in isolation and it can be observed from Table 2.1 that they are almost always conjugated or inflected depending on the context in which they occur. This may pose difficulties when extracting words from language samples especially when word frequency and density must be taken into account because different inflections will lead to additions, deletions or substitutions in more than one phoneme and each inflection will have a different grammatical meaning. For example, for the word ‘wrote’ in Arabic /kætæb/, the present form meaning ‘I write’ would be /æktʊb/ while the present form for ‘he writes’ would be /jɪktʊb/. In this example we can see how the first vowel changed from /æ/ to /ɪ/ when the /j/ was added to signal the change from ‘I’ to ‘he’. Another example showing how change in gender would yield different features is the word meaning ‘sitting’. With male gender, this is /ʒæːlɪs/ and with the female gender it is /ʒæːlsæ/. In this example, the vowel /ɪ/ was omitted and the vowel /æ/ was added at the end of the word. An example of how gender may also alter consonantal features is the word /mæd/ meaning 'stretched'. This form of the word would be used when referring to a male, but if when referring to a female, the word would become /mæddæt/ in which the final consonant (plosive) changed from being released to being unreleased due to the process of gemination. These alterations in word roots that occur due to conjugations and inflections make it difficult to directly select words from spontaneous language samples and use them in speech and language tests in the conjugated form.

2.1.7 Saudi Arabic and its dialects

Within Saudi Arabia itself, many dialects are present. According to Prochazka (1988), the dialects of Saudi Arabia can be divided into two groups: a) dialects of southern Hijaz and Tihama, b) dialects of Najdi and Eastern Arabia.

The name Southern Hijaz is a continuation of Northern Hijaz and these two form together the geographical area between Jordan and Yemen and includes the dialects of the following regions: Al-Qahabah, Rufaidah, Abha, Bal-Ahmar, Tanumah, Bal-Qarn, Ghamid, Al-Qauz, and Sabya. The dialects of the Najdi and Eastern Arabia however, are spoken in the rest of Saudi Arabia and are better known than those in the South West of Saudi Arabia. Geographically, the area covered by this group of dialects is huge and is bounded by Hijaz on the west, North and South Yemen and Oman on the south, the Gulf regions on the east and Iraq and Jordan on the north. This area also includes mountains such as Jabal Tuwaiq and Jabal Shammar as well as desserts such as the Empty Quarter, Great Nafud, and Dahna. Villages and towns are found where water is available. These include the dialects of the following regions: Rwaili, Hayil, Al-Qasim, Sudair, Riyadh, Hofuf, Bishah, and Najran. The term Najdi can be used alternately in a linguistic or geographical sense. Geographical Najd refers to Central Arabia where Najdi dialects are spoken. However, Najdi dialects are also spoken outside Najd region and stretch as far as the Syrian Desert (Prochazka, 1988).

Given that the Najdi dialect is widely spoken inside and outside of Riyadh, this dialect was chosen for the development of the current speech perception test.

2.1.8 Language Sampling

Language sampling is considered one of the early robust methods used for evaluating language disorders. However, due to the huge amount of time required to record, transcribe, and analyse language samples (MacWhinney, 1996; Paul & Cascella, 2007), it is not widely used especially among clinicians. Since the beginning of the study of spontaneous language production, language sampling has undergone many changes and different methods have been applied to collect spontaneous language samples. Diaries and biographies, inspired by the work of Charles Darwin, were used initially to document the development of children's language. However, due to the limitations of this procedure in keeping records of the rapidly growing language of children, the use of the tape recorder to record language samples emerged and data was then transcribed either by hand or through a typewriter. Brown was the first person to use this technique and share his language data with others when he and his students recorded the language development of three children which was transcribed and shipped to other researchers. Later on when computers came into our world, they allowed data entry and analysis through standardised techniques. One of the major databases that is currently used for exchanging language data is the CHILDES system (MacWhinney, 1996). This system currently has a wide variety of language samples from children with normal language development and children with language disorders of different ages and in different situations. Not only does it include English language speaking children but also children speaking other languages around the world such as Chinese (Mandarin and Cantonese), Danish, Dutch, French, German, Greek, Hebrew, Hungarian, Italian, Japanese, Turkish, Swedish, and Russian, in addition to many other languages (MacWhinney, 1996).

The CHILDES system has been used for extracting language data to aid in the construction of language tests. One test that has been constructed on the basis of data from the CHILDES system is the Lexical Neighbourhood Test by Kirk et al. (1995). Another version of this test that has been developed in Cantonese Language (Yuen et al., 2008) also used language samples from the CHILDES system.

Although spontaneous language sampling has the highly desirable property for assessing children's language and of reflecting children's language ability in everyday communicative situations, there are many issues surrounding this method of data collection. Examples are the length of the sample, the type of stimulus used to elicit samples (Gazella & Stockman, 2003), variability in the language samples as a result of inconsistent materials used and different outputs from children (Thomas, 1989).

Regarding sample length, a 15 minute sample duration is usually used for collecting spontaneous language samples especially from children aged 3 to 5 years as this size of sample typically contains 50 to 100 utterances which is considered enough for analysing this age group's language development (Paul & Cascella, 2007). However, the difficulty not only lies in collecting the sample but also transcribing it later on. Therefore, in order to encourage the use of language sampling in the assessment of language abilities, Heilmann, Nockerts, and Miller (2010), examined the reliability of short language samples when compared to long samples. Three sample durations (1, 3, 7 minutes) were compared with young children (2.8-5.11 years) and older children (6.0-13.3 years). The language samples were elicited in two contexts; conversation and narrative. A protocol was developed for eliciting responses from children, and speech–language therapists who participated received 6-8 hour training on this protocol prior to collecting the samples. The protocol included methods to initiate topics, possible topics to bring into the sample, rules for starting the sample and ways to keep the child talking on the topic. Results revealed that the difference between short samples (1 and 3 minutes) and long samples (7 minutes) was not significant especially for the younger group which means that short samples can be considered as stable and reliable as long samples. It was also reported that there are several factors that may affect the complexity of language produced by children during language sampling such as familiarity with the examiner and sampling context (narrative vs. conversation). It appeared that children tend to use less complex language prior to establishing rapport with the examiner and while describing simple rather than complex episodes during story telling. Additionally, children described emotional events in more detail than non-emotional events. Another study by the same author reported that children tend to produce more complex language in narratives rather than conversation. However they did clarify that this may be the case only for older children rather than young children (Heilmann, Miller, & Nockerts, 2010).

When considering the type of stimulus presentation in gathering language samples (audio-only vs. audio-visual), Gazella (2003) studied the effect of mode of stimulus presentation on sample size and complexity. Children in this study were randomly assigned to two groups. Both groups were presented with the same story but one group of children listened to the story through the audio-only modality without the presentation of pictures or illustrations and the other group listened to the story while watching a corresponding video narration. Results revealed that there was no significant effect of mode of presentation on size of language output or complexity by the children in the two groups, even though children who were in the audiovisual group seemed more attentive during the audiovisual presentation than children in the audio-only group.

Although spontaneous language samples surpass other methods such as elicited imitation and formal language testing in providing a more natural view of the child's language in daily settings, a problem that this method of language data collection poses is the wide variability of responses produced by children due to the absence of guidelines for sampling (Evans & Craig, 1992; Fujiki & Willbrand, 1982; McFadden, 1996). This results in the problem that samples lack standardization and uniformity because children respond differently to different toys and pictures that may be presented to elicit the spontaneous language sample. In an attempt to address these difficulties, a study comparing language samples elicited through free play and interview was conducted by Evans (1992). In the free play session, the child was presented with a set of toys from which he/she was allowed to choose the toy they preferred to play with during the 15 minute session. While in the interview, the child was told to talk about his/her "family, school and free activities". The interview session was also 15 minutes in length. The examiner provided certain prompts and asked the child open-ended questions in order to elicit responses. Results revealed that children were more responsive during the interview context and that this context resulted in a more reliable sample and greater consistency between children as opposed to the free play session.

From the above studies, it is clear that the language sampling procedure can be a valid and reliable method for the collection of language data that can be carried out with the use of free play, interview and conversation or story retelling. Moreover, it seems that sampling does not have to be lengthy in order to be reliable. Furthermore, even though there appears to be no effect of modality of presentation on the amount of talking generated by children, it seems likely that the aid of visual presentation when using narratives as a form of language sampling would be more entertaining for children especially young ones and may keep them more interested in the task and topic.

2.1.9 Considerations in speech perception testing

Many factors may influence the outcomes of speech perception assessments. These include the subject, clinician, task, and environment (Boothroyd, 2004). The most important of these however, is the task factor, the basis of the current study. This factor requires the greatest consideration probably due to the effects of maturation and language on test outcomes (Eisenberg et al., 2005).

Speech assessment measures vary from closed set to open set response formats, live voice to recorded presentation, and auditory visual to auditory only administration. In closed set tasks, a limited number of choices are available to the listener and can be used for speech discrimination or identification tasks. A range of response types can be used in such tasks that can vary according to the age and ability level of the subject. For example, in a two alternative discrimination task, the subject may be asked to respond by saying whether or not the two stimuli are same or different, while in an identification task, a group of pictures may be presented and the subject asked to point to the picture that corresponds to the word that was heard, either with or without repeating it. Stimuli for these tasks typically include words and nonsense syllables.

Such phoneme identification tests are useful for obtaining information about the perception of speech features (voicing, manner, and place) and do not rely on higher level cognitive or linguistic processing, such as lexical knowledge. In contrast, no response alternatives are available in open-set tasks, resulting in an unlimited number of choices. Open set word and sentence recognition tests thus arguably require higher level cognitive and linguistic abilities than closed set tasks and are more representative of real life listening situations (Eisenberg et al., 2005). Since the current study is concerned with developing a lexical neighbourhood test in the Arabic language, an open set test would seem more appropriate than a closed set test as it allows lexical access. Also, the fact that closed set tests have restricted response choices means that each target word must have at least 3 neighbours in a closed set task of 4 choices. Consequently, this requirement is not suitable for the current test as the words which have low neighbourhood density may have less than 3 neighbours. Moreover, regarding response format, repetition of test stimuli would provide more information about what the subject heard rather than pointing to a certain picture especially given that the presence of certain choices in front of the subject may restrict the child to producing one of the available choices rather than what they actually heard.

2.1.10 Project aim

The aim of this research project is to develop a version of the Lexical Neighbourhood Test in the Arabic language. Due to the unavailability of language samples in the Arabic language on the CHILDES system or any other database, it was necessary to collect spontaneous language samples in order to extract the words required for constructing this test. Normal children for this purpose are defined as those having normal I.Q., hearing and learning ability and not receiving any speech and language or special education services (McFadden, 1996). This sampling was in 3-5 year old children, whose language levels were expected to be comparable to somewhat older children with cochlear implants. A sample size of 70 was chosen because it was comparable to the sample size used in another study that was concerned with developing the same test in Mandarin (Yuen et al., 2008).

2.2 Method

2.2.1 Language sampling

2.2.1.1 Participants

76 children were recruited from 5 nurseries and kindergarten schools in Riyadh, Saudi Arabia (3 private schools and 2 public schools). Criteria used for children who were chosen for language sampling included having a Saudi nationality, speaking in a Najdi dialect, normal hearing, not attending special education classes and within the age range of 3 to 5:11 years. For each child, the sample recording duration ranged from 15-35 minutes with an average of 20 minutes. From those 76 children, 4 children were excluded; 3 for not finishing the protocol and 1 for not being Saudi and for speaking in a dialect other than Najdi. This resulted in language samples from 72 children. It is essential to note that one child had both Najdi and Hijazi words and another child had both Najdi and gulf words. Thus, only the words that were in Najdi were chosen from their sample.

2.2.1.2 Materials and equipment

Materials for collecting language samples included two books (Amery & Cartwright, 2004; Rogers & Cartwright, 2008) with pictures and scenes about daily living activities which the children were asked to talk about. Also, children were given a task of retelling a story from a sequence of pictures, using three short stories that were constructed in a specific way to include lexical neighbours (Appendix 7.2). Recording was done using a Roland R09-HR digital recorder.

2.2.1.3 Analysis

After collecting the language samples, these were transcribed both phonetically and orthographically. Where words were misarticulated by children, the errors were retained in the transcription and the word was additionally labelled with the correctly pronounced form.

The number of words that were transcribed was 28979. The total number of unique words was 4385. Divided into monosyllabic, bisyllabic and multisyllabic classes, the number of words in each class was 641, 2773 and 971 respectively. The dominance of bisyllabic words implied that the development of a monosyllabic or multisyllabic test may not be desirable. Another issue was the extent to which Kirk's definition (1995) of hard and easy words would be applicable to Arabic language. The reason for these uncertainties is the previously mentioned point that Arabic and English languages descend from different language families and are very different in their structure. So, would defining lexical neighbours by the substitution, omission and addition of one phoneme be viable? Should the definition be adjusted to include changing two phonemes instead of one if the first definition was not applicable to the Arabic words?

In order to extract lexical neighbourhoods using the definition derived by Kirk et al. (1995), a custom program was built in Visual Basic to execute this function. The analysis revealed an additional difficulty in applying Kirk's method to Arabic directly. This arose where words had prefixes and suffixes signalling gender, tense, or number/plural. These prefixes and suffixes often included one phoneme. For example: the word /ɪʃræb/ which means 'drink' in English had the following neighbours: /tɪʃræb/, /jɪʃræb/, /nɪʃræb/ indicating the female, male, and plural form of the same word. Therefore, for some words a phonetically defined neighbour had the same meaning as the original word. It seemed appropriate to consider these inflected forms as representing the same lexical item, and hence inappropriate to count these inflections as mutual lexical neighbours. To avoid miscalculating neighbourhood density, the prefixes and suffixes were removed while preserving the original pronunciation. The advantage of removing the prefixes and suffixes before entering them into the program was retaining a list of 'unified' words. By 'unified' we mean that all the words would have no gender or person markings. A disadvantage of this approach was that when it was applied to some verbs, the verb tenses changed from the present tense to the imperative form. This was unavoidable because it was the only way in which we could preserve the original pronunciation. By applying this method of 'unification' all the inflected forms were treated as the same lexical item for neighbourhood density purposes.

After 'unifying' the data and removing the misarticulated words, the number of words was reduced from 4385 to 2526; 416 monosyllabic, 1651 bisyllabic, and 459 multisyllabic. The words were then divided into three categories: words with neighbours, words without neighbours, and loan words (i.e. words that have been adapted from English language such as 'cake'). The distribution of neighbours and word frequency for words with differing syllable length is displayed below in Figure 2.1 and Figure 2.2 for different age groups. The age range is from 3 to 5:11 years and children are divided into 6 groups each spanning a 6 month age range (i.e. 3-3:5, 3:6-3:11, 4-4:5, 4:6-4:11, 5-5:5, & 5:6-5:11).

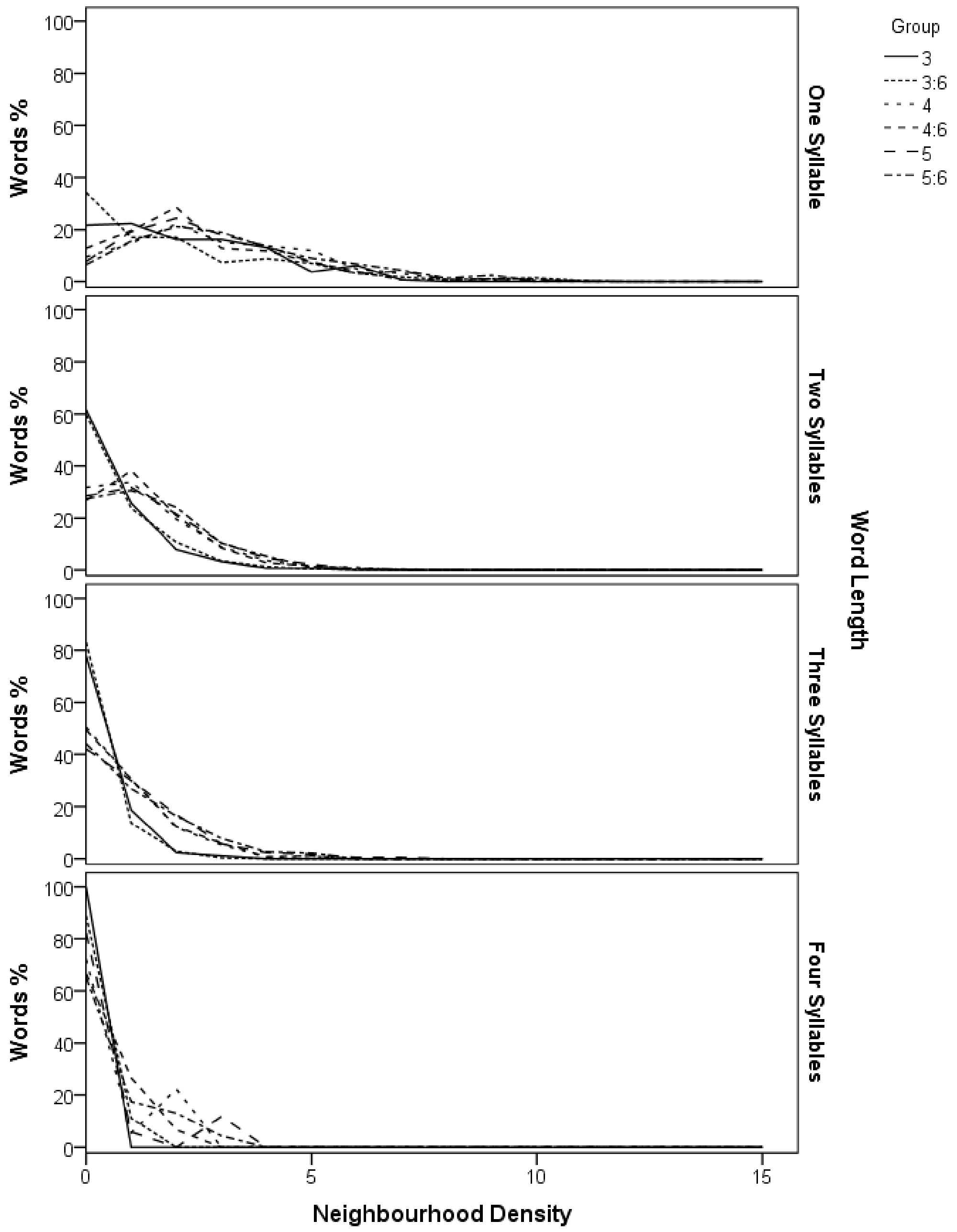


Figure 2.1: Distribution of neighbourhood density for 1, 2, 3, & 4 syllable words for all age groups.

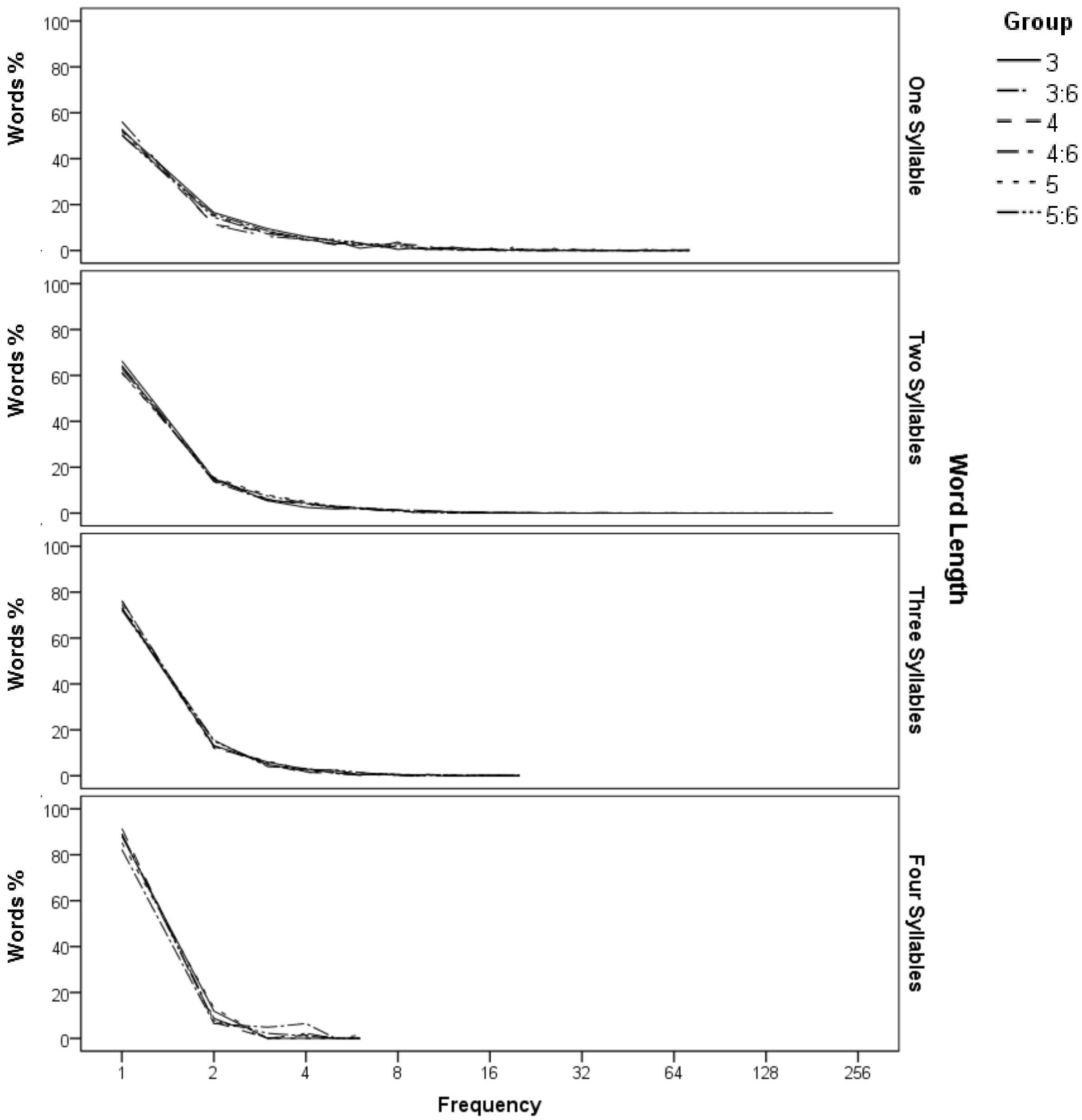


Figure 2.2: Distribution of word frequency for 1, 2, 3, & 4 syllable words for all age groups.

2.2.2 Test Construction

The median was calculated for the neighbourhoods and the frequencies of all three categories: monosyllabic, bisyllabic, and multisyllabic words separately. For the monosyllabic words the frequency count ranged from 1-377 with a median of 3.5 while the neighbour count ranged from 0-13 with a median of 2. For the bisyllabic words the frequency count ranged from 1-779 with a median of 2 and the neighbourhood count from 0-9 with a median of 0. Finally, for the multisyllabic words the frequency count ranged from 1-112 with a median of 1 while the neighbourhood count ranged from 0-3 with a median of 0. The construction of a multisyllabic test was not attempted due to the low number of neighbours available.

Since the median for neighbourhood density for bisyllabic words was 0, Kirk's approach of using the median to divide high from low density was not workable. Another approach that was used by Yuen et al. (2008) for constructing the Cantonese LNT was the use of percentiles for differentiating high density from low density words. Following this approach, percentile cut-offs were used instead. For the monosyllabic word list, cut-offs for high and low frequency were set at the 65th and the 60th percentile while density cut-offs were set at the 70th percentile and 55th percentile. For the bisyllabic word list, the frequency cut-offs were set at the 85th and 70th percentile, while neighbourhood density cut-offs were set at the 90th and 60th percentile.

It was possible to select 100 monosyllabic words and 100 bisyllabic words for test stimuli. For each word class, half the words were hard and half were easy. Both easy and hard words will ultimately be divided into two lists, each containing 25 words, this being done by matching the two lists for word frequency and neighbourhood density. Inspection of the easy and hard word lists of the monosyllabic and bisyllabic tests revealed that the words that were included in the monosyllabic word test seemed unsuitable because some items were loan words and thus may not be familiar to all children. This may have been due to the small number of monosyllabic words. Hence, we decided to use only the bisyllabic test in this study (Appendix 7.3). Table 2.2, Figure 2.3, and Figure 2.4 display the percentiles and ranges for word frequency and neighbourhood density for bisyllabic words.

An additional set of 50 bisyllabic words were chosen that lay between the easy words and the hard words in both frequency and neighbourhood density (Appendix 7.4). These ‘intermediate’ 50 words were used for practice purposes.

Table 2.2: Word frequency and neighbourhood density for bisyllabic words.

	Word Frequency		Neighbourhood density	
	High	Low	High	Low
Percentile	> 85	< 70	> 90	< 60
Range	10-779 words	1-4 Words	2-9 neighbours	0 neighbours

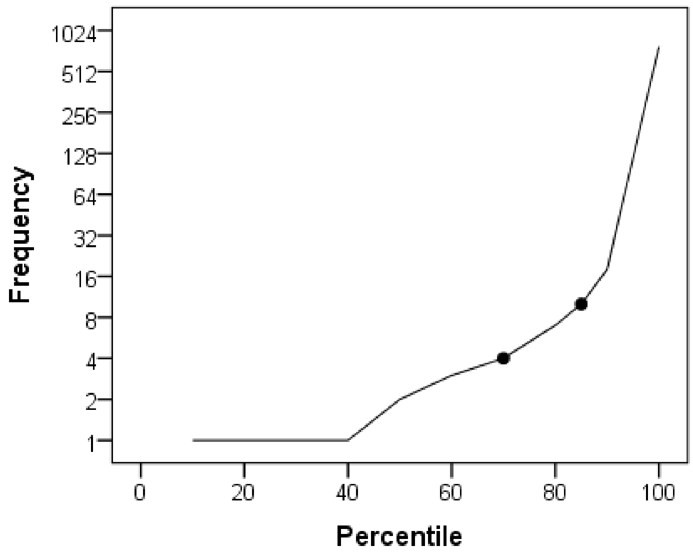


Figure 2.3: Percentiles and corresponding word frequencies.

The filled circles represent the percentile cut-offs used for generating the high frequency and low frequency bisyllabic test words.

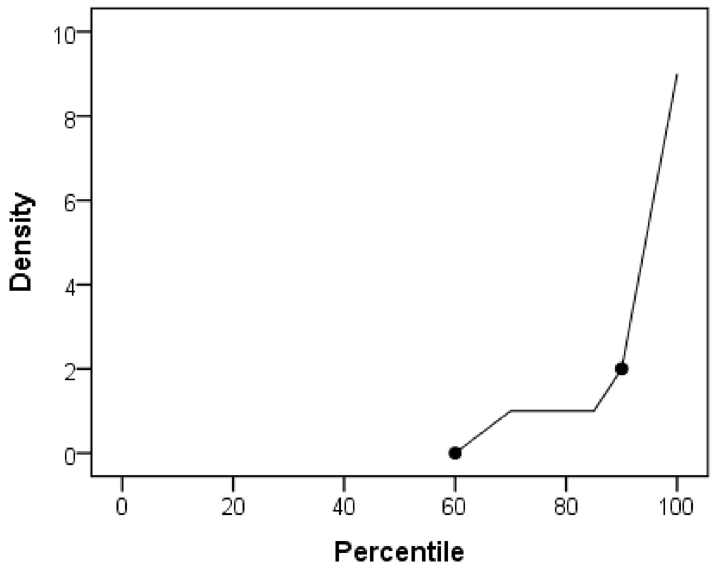


Figure 2.4: Percentiles and corresponding neighbours.

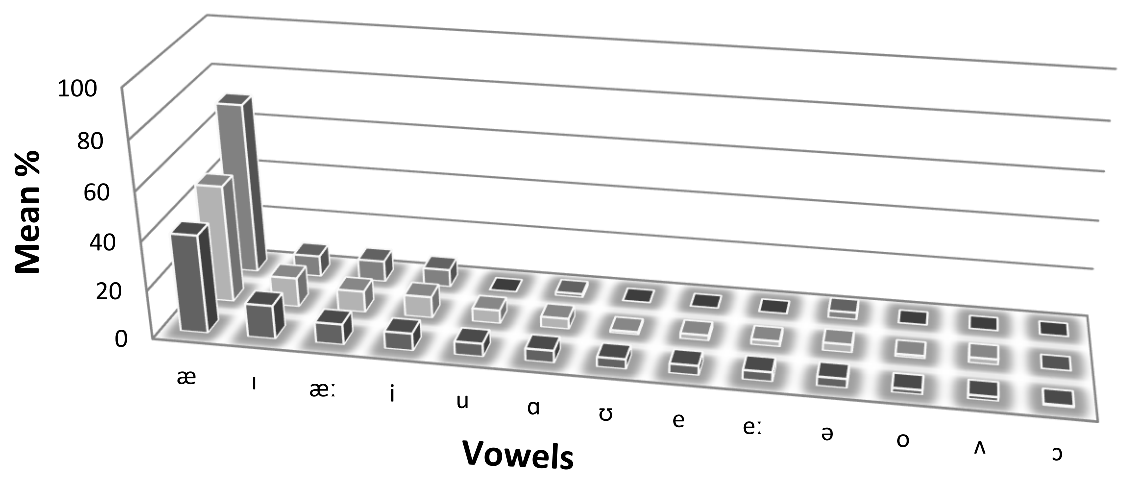
The filled circles represent the percentile cut-offs used for generating the high density and low density bisyllabic test words.

2.2.3 Recording methods

The test stimuli and the additional 50 ‘intermediate’ words were then recorded by a female Arabic speaker from Saudi Arabia. The speaker produced the words in a carrier phrase so as to simulate the productions of the words in a daily conversation. The carrier phrase ‘say the word …’ included the instruction to repeat the word that is heard every time so as to remind the child to produce the word when s/he hears it. The recording took place in an anechoic chamber with a B&K 2231 sound level meter fitted with a 4190 microphone cartridge and set for a linear frequency response from 10 Hz - 20 kHz. The AC output from the sound level meter was fed to a Sony 60ES DAT recorder (sampling frequency 44100Hz, 16 bit quantisation) and the digital output from the DAT recorder was fed to the digital input of an M-Audio Delta 66 sound card in the Dell Optiplex PC.

2.2.4 Distribution of speech sounds across language samples

The frequency of occurrence of the consonants and vowels in the language samples collected across all age groups was examined and compared to that of the easy and hard word lists in order to investigate phonetic balancing. Figure 2.5 displays the distribution of frequency expressed as percentages for the vowels across the language samples as well as for the easy and hard lists.



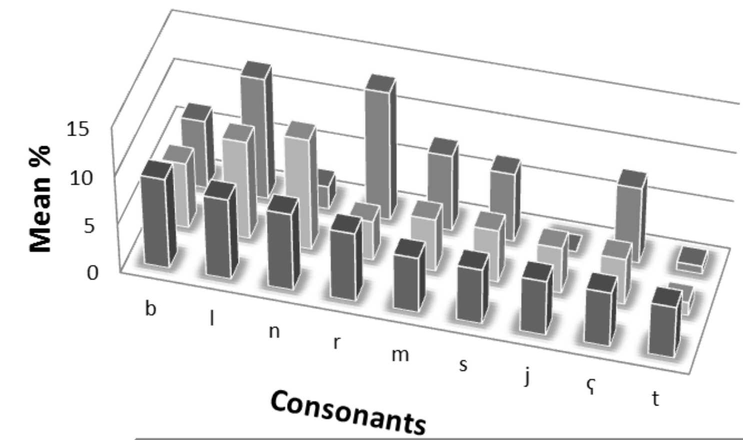
	æ	ɪ	æː	i	u	ɑ	ʊ	e	eː	ə	o	ʌ	ɔ
Language sample	40.42	13.84	8.51	7.14	5.44	5.03	4.03	3.90	3.84	3.74	1.79	1.65	0.67
Easy List	48.35	12.09	8.79	8.79	5.49	4.40	1.10	2.20	2.20	3.30	1.10	2.20	0.00
Hard List	71.01	8.70	8.70	7.25	0.00	1.45	0.00	0.00	0.00	2.90	0.00	0.00	0.00

Figure 2.5: Bar chart showing the average frequencies of each vowel across the 3 age groups in the language sample and the frequency of each vowel in the easy and hard lists expressed as percentages.

The frequencies for all vowels are considered similar between the three age groups for the connected speech and the differences are all within 2%. Not all vowels however are present in the easy and hard lists, the vowel /ɔ/ for instance is not present in the easy lists and the vowels /u/, /ʊ/, /eː/, /e/, /ʌ/, /ɔ/ are not present in the hard lists. Additionally, when comparing the frequencies of occurrence of the vowels between connected speech and the test lists, the percentage of occurrence of the vowels in the easy lists approximates that seen in connected speech but this is not true for the vowels in the hard list as only 3 vowels from the hard list approximate those found in the language samples.

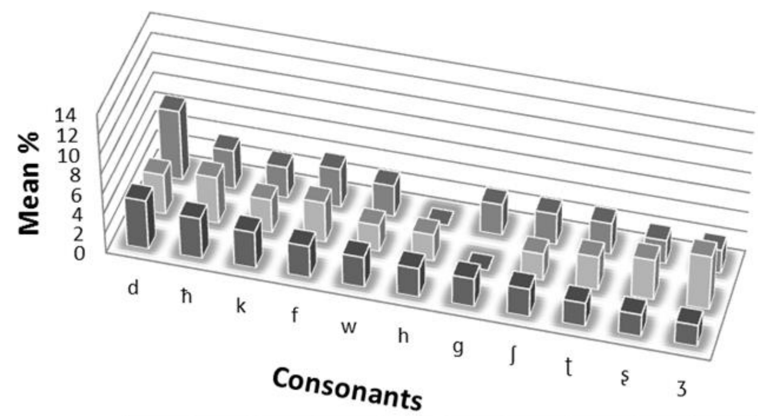
As with the vowels, a similar pattern was observed in the consonants. The frequencies of consonants across age groups were comparable and the differences were within 2%.

Regarding the test lists, some consonants were not in the easy list or the hard list. The consonants / ɖ/, /g/, /ʔ/and /ð/ were not included in the easy list and the consonants /h/, /j/, /z/, /ʐ/, /ʔ/, / θ/and /ð/ were not included in the hard list. Unlike the vowels however there was quite high consistency between the frequency of occurrence of the consonants in connected speech and in the easy and hard lists. For instance, 14 consonants had similar frequencies of occurrence in connected speech, easy lists, and hard lists. Six consonants in the easy lists had a frequency of occurrence resembling that in connected speech and 3 of the consonants in the hard list had frequencies of occurrence that were similar to those found in connected speech. Figures 2.6, 2.7, and 2.8 show the mean percentage of frequencies of occurrence of consonants in the language samples as well as the percentage of frequencies of occurrence of consonants in the easy and hard lists. The consonants were divided into 3 figures based on their frequency of occurrence in the language samples. Figure 2.6 includes the frequencies above 5 %, Figure 2.7 contains the frequencies from 2-4%, and Figure 2.8 includes the frequencies that are less than 2%.



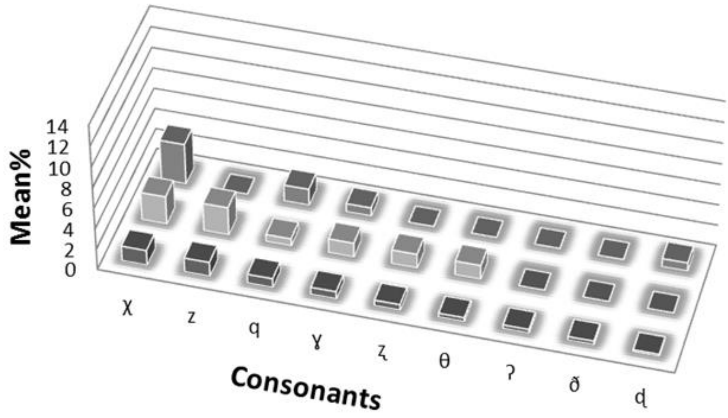
	b	l	n	r	m	s	j	ʕ	t
Language sample	9.23	8.24	7.88	7.02	5.64	5.60	5.57	5.55	5.25
Easy List	6.67	10.00	11.33	4.00	5.33	5.33	4.67	4.67	1.33
Hard List	6.98	12.40	2.33	13.18	7.75	6.98	0.00	7.75	0.78

Figure 2.6: Bar chart showing the average frequencies of each consonant across the three age groups in the language sample (expressed in percentages) and the frequency of each consonant in the easy and hard lists which have a frequency of more than 5%.



	d	ħ	k	f	w	h	g	ʃ	ṭ	ṣ	ʒ
Language sample	4.92	4.07	3.63	3.19	3.03	2.89	2.83	2.79	2.36	2.19	2.13
Easy List	4.00	4.67	3.33	4.00	2.67	2.67	0.00	2.67	3.33	4.00	5.33
Hard List	6.98	3.88	3.10	3.88	3.10	0.00	3.10	3.10	3.10	2.33	2.33

Figure 2.7: Bar chart showing the average frequencies of each consonant across the three age groups in the language sample (expressed in percentages) and the frequency of each consonant in the easy and hard lists which have a frequency of 2-4%.



	χ	z	q	ɣ	ʐ	θ	ʔ	ð	ɖ
Language sample	1.41	1.34	0.84	0.67	0.52	0.36	0.34	0.33	0.17
Easy List	2.67	2.67	0.67	1.33	1.33	1.33	0.00	0.00	0.00
Hard List	3.88	0.00	1.55	0.78	0.00	0.00	0.00	0.00	0.78

Figure 2.8: Bar chart showing the average frequencies of each consonant across the three age groups in the language sample (expressed in percentages) and the frequency of each consonant in the easy and hard lists which have a frequency of less than 2%

2.2.5 Distribution of speech sounds for easy and hard lists

Speech sound distribution between word lists may have an impact on word recognition especially if one list contained speech sounds that were more easily identifiable than sounds which are otherwise difficult to perceive. Because the frequencies of individual sounds were often very small, this data was not well-suited to a Chi-squared analysis. Therefore, sounds were grouped according to features prior to conducting the statistical analysis. To investigate the phonemic content of both the easy and hard lists, the distributions of consonant place, voicing and manner were compared between lists. This revealed that there was a significant difference between easy and hard lists for the distribution of manner [$\chi 2$ = 14.22, df= 4, p=.007], but not for place [$\chi 2$ = 4.72, df= 6, p=.58] or voicing [$\chi 2$ = .76, df= 1, p=.383]. Further inspection of the manner of production of consonants revealed that the differences between easy and hard words exist with regards to fricatives and trills. The relative frequency of fricatives was much higher in the easy words (42%) than the hard words (32%) while trills were more frequent in the hard words (14%) than the easy words (4%). Figure 2.9 shows the variations in consonant features between easy and hard words.

In terms of vowel variation, the easy list included 11 different vowels as opposed to 7 vowels in the hard list. Inspection of the relative frequencies of vowels as a function of duration within the easy and hard word lists showed that there was a significant difference in the numbers of short and long vowels present in both lists [$\chi2 = 5.49$, $df= 1$, $p=.02$]. Further examination revealed that the long vowels had a higher frequency in the easy words (26%) than the hard words (13%) while the short vowels were observed more frequently in hard lists (87%) than the easy lists (74%). Vowels were also investigated for place of production (i.e. front, central, back) and height (i.e. low, mid, high). Chi-squared analysis revealed that there was no significant difference between easy and hard words in the distribution of front-back articulation [$\chi2 = .26$, $df= 2$, $p=.878$] but a significant difference was found in the distribution of height [$\chi2 = 7.95$, $df= 2$, $p=.02$]. Exploration of relative frequencies of the vowel height using a 3-way classification showed that low and mid vowels were more frequent in the hard lists (66% and 24%) than in the easy lists (53% and 22%). Conversely, high vowels were more frequent in the easy lists (25%) than the hard lists (10%). Figure 2.10 shows the variations in vowel features between distribution of height [$\chi2 = 7.95$, $df= 2$, $p=.02$].

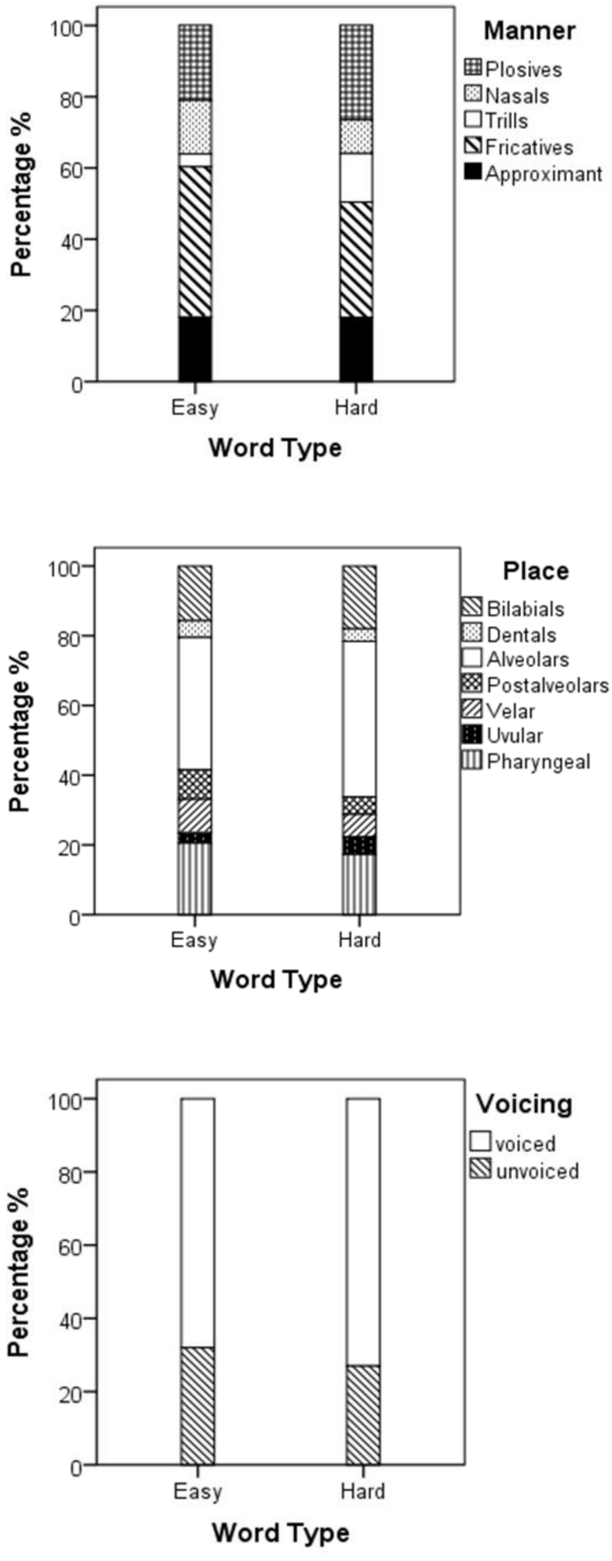


Figure 2.9: Relative frequencies of consonant characteristics expressed in terms of percentages for easy and hard words.

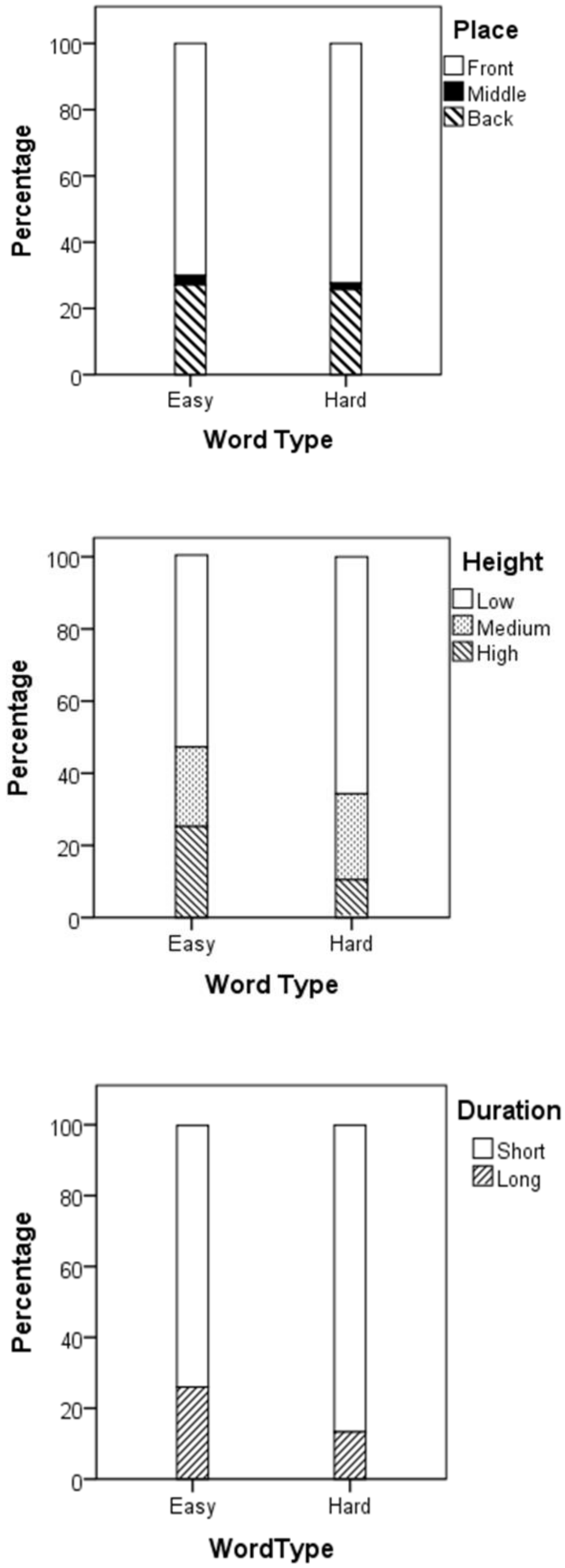


Figure 2.10: Relative frequencies of vowel characteristics expressed in terms of percentages for easy and hard words

2.3 Discussion

There were several challenges faced in the development of the current test. These included unavailability of language samples for Saudi children from which the test could be constructed, lack of an ideal method for dealing with conjugated or inflected words, and presence of various dialects in Saudi Arabia.

The collection of the language sample was straightforward, but analysis of the sample revealed some difficulties in the use of the lexical neighbourhood framework. First, most of the words in the samples were conjugated or inflected and the method used here to remove those inflections meant that some of the verb tenses had to be changed to the imperative form to preserve the original pronunciation. It is important to note that the solutions that were used in this experiment for overcoming the problems faced with inflections, prefixes, and suffixes may not have been the ideal method for treating inflected words. Thus, a fixed and approved method should be established so other future tests can be constructed without being affected by different methods for removing conjugations or inflections.

The second part of this research involved the construction of a word recognition test using bisyllabic words in the Najdi dialect (spoken in Riyadh). Developing this test in a single specific dialect was crucial to avoid inaccurate assessment of speech perception skills caused by dialectal differences among Saudi Arabic speakers. An advantage of having a speech perception test that controls for dialects is that all selected words are familiar to children within that geographical area. A disadvantage however, is that it cannot be applied throughout the whole country. A solution to this problem may include collecting language samples from the main regions which cover the 5 major dialects spoken in Saudi Arabia and selecting the words that are common among them. Ashoor and Prochazka (1985), developed a Saudi speech perception test and attempted to overcome the problem of dialects by using

Modern Standard Arabic (MSA) and had the familiarity of the test words evaluated by students representing different Saudi Arabian towns in order for it to be applicable across Saudi Arabia. However, as mentioned previously, MSA is only used in formal situations but not in daily conversations and therefore may not reflect a child's performance in everyday situations.

It is important to note that only a bisyllabic test was achievable in the current study whereas all other versions of the LNT have managed to establish at least a monosyllabic and a bisyllabic test (Kirk, 1998; Kirk et al., 1995, Liu et al., 2011; Wang et al., 2010; Yuen et al., 2008). This is due to constraints of the Arabic language; monosyllables are very rare and consequently, there are not enough monosyllabic words to construct a monosyllabic word test, especially in colloquial Arabic (Kishon-Rabin & Rosenhouse, 2000).

In Kirk's LNT (Kirk et al., 1995), the median was used to differentiate between high and low cut-off points for word frequency and neighbourhood density. For the current test however, medians were not feasible because of their low values. In order to more clearly differentiate between hard and easy words, percentiles other than the median were adopted to allow a larger difference between the high and low frequencies and neighbour counts. This method was also used in the development of the Cantonese Lexical Neighbourhood Test for the construction of a disyllable test due the high number of disyllables without neighbours (Yuen et al., 2008). By using percentiles, it was possible to develop a test that included 50 easy words and 50 hard words.

Inspection of speech sound distribution between hard and easy lists showed that there were some differences regarding manner of production for consonants and duration for vowels. It is essential to note that these differences may have an impact on word identification. Although previous studies have shown that CI children tend to perceive manner and voicing better than place and nasality (Bouton et al., 2012 & Tye-Murray et al., 1995), there is also evidence that they tend to struggle in discriminating between some speech features more than others. For example, CI children discriminate between sibilant fricatives /s/ and /ʃ/ with 60% less accuracy than NH children (Summerfield et al., 2002). This discrepancy between CI and NH children has been attributed to the poor spectral resolution provided by the CI device (Friesen et al., 2001). Given this information, even though the frequency of fricatives was higher in the easy words, the frequency of sibilant fricatives was higher in the hard words which may have played a role in making the hard words more difficult to perceive. Hence, future experiments should take account of consonant and vowel distributions between easy and hard lists to rule out the impact of factors other than word frequency and neighbourhood density in the identification of words.

Although phonetic balancing was not considered in the construction of the ALNT, frequency of occurrence of vowels and consonants was inspected in both the language samples and the easy and hard lists to further examine if distribution of speech sounds was similar between the two lists. In order for the test lists to be phonetically balanced, frequencies of vowels and consonants in the test lists should resemble those in connected speech. The distribution of the vowels in connected speech was similar to that in the easy list but not the hard list while for the consonants there was overlap in the distribution of some phonemes between connected speech, easy, and hard lists but still the number of the remaining consonants that approximated those observed in connected speech was higher for the easy list. This may have been due to the easy words being more common than the hard words.

A limitation to the current study was that the ALNT was only constructed in one dialect and this makes the test inapplicable in other regions of Saudi Arabia where different dialects are spoken.

2.4 Conclusion

The current study aimed at developing a clinical speech perception test that could be used with Saudi Arabian children with cochlear implants. The test was based on the same theory as the English Lexical neighbourhood Test developed by Kirk et al. (1995); the Neighbourhood Activation Model (NAM). Even though there are huge differences between the English and Arabic languages with regards to language structure, it was possible to develop an Arabic Lexical Neighbourhood Test that was consistent with the NAM. However, specific universal measures should be developed to deal with conjugated words to avoid methodological biases in future test development.

After the successful development of the ALNT, the next chapter will examine the suitability of this test in normal hearing children in two conditions: noise conditions and cochlear implant simulations. Testing was administered in these two conditions to avoid ceiling performance and to get an idea of the likely performance of paediatric cochlear implant users on the ALNT.

3 Chapter three: Administration of the Arabic Lexical Neighbourhood Test on normal hearing children in both noise and vocoded speech conditions

3.1 Introduction

Speech recognition is a complex task that requires both detailed spectro-temporal information from the sensory periphery and strong central pattern recognition ability. Moreover, speech recognition performance is age-dependent and it has been shown that children's performance improves as they grow older (Eisenberg, Shannon, Martinez, Wygonski, & Boothroyd, 2000). Evidence has shown that this progressive improvement is at least in part related to peripheral rather than central factors. On the one hand, infants are born with fully-functioning cochleae (Eggermont, Brown, Ponton, & Kimberley, 1996) and brainstem myelination and physiologic function have reached maturity by the perinatal period (Moore & Linthicum Jr, 2007). On the other hand however, children's performance in speech recognition reaches adult performance at approximately 8 years in quiet conditions and at 11 years in noise conditions (Stuart, 2005).

Several studies of speech perception in both adults and children have used a model that is designed to mimic the listening experience of individuals using cochlear implants (CI) (Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995). This is done through the use of noise vocoded speech that simulates CI stimulation in normal hearing listeners (NH). Noise vocoders allow the assessment of the number of channels required by NH individuals to achieve optimum speech understanding levels (Dorman, Loizou, Kemp, & Kirk, 2000).

The previous chapter, describes how the Arabic Lexical Neighbourhood Test (ALNT) was developed for clinical use with children using CIs. However, prior to using this test on children using CIs, the ALNT was used with NH children in two conditions: in noise and under spectrally degraded speech via 4 and 8 channel vocoders simulating a CI. The noise condition was used to control for ceiling effects while the vocoded speech conditions were utilized in order to explore the suitability of the test materials for children using CIs. Reasons for using CI simulations were that the ALNT has been constructed to be used as a clinical assessment tool with CI children. So, applying the test on NH children in spectrally degraded conditions may guide expectations for CI children's performance. Furthermore, the reason for using two different channel numbers was to ask whether the ALNT could be used to detect a meaningful difference in the quality of information from a simulated CI.

Therefore, the aim of the current group of studies was to explore open set word recognition performance on the ALNT in 5 year old NH children in both noise and CI simulation conditions, to investigate whether lexical effects are present in noise and under spectrally degraded conditions, and finally to determine the test-retest reliability of the ALNT by applying it twice on NH children in noise.

The LNT has been developed in both English and Chinese languages and has also been used with both CI and NH children. The following sections will provide an overview about the use of the LNT those two languages.

3.2 Application of the Lexical Neighbourhood Test in English

The US English Lexical Neighbourhood Test (LNT) was administered to children with cochlear implants in the quiet. Word scoring was based on the number of words repeated correctly while phoneme scoring was based on the number phonemes repeated correctly in each word. Word scores were significantly higher on easy words than hard words. However, phoneme scores did not differ between easy and hard lists. This was consistent with the prediction of the Neighbourhood Activation Model (NAM) that word recognition is influenced by neighbourhood density and word frequency. The lack of a significant difference in phoneme recognition however, led the authors to conclude that the lexical properties of frequency and density do not have an effect on phoneme recognition. In other words, if words were perceived as a sequence of isolated sounds then phoneme scores would be similar to word scores. However, since easy words received higher scores than hard words, then this demonstrates than CI children perceive words in the context of other similar words in their lexicons. Hence, there must be factors other than the difficulty of phoneme identification involved in the perceptual processes underlying word identification (Kirk, 1998; Kirk et al., 1995).

However, because the selected words were highly controlled to have an inverse co-variation of density and frequency (i.e. high frequency is tied with low neighbourhood density in easy words and low frequency is tied with high neighbourhood density in hard words), these materials preclude a rigorous test of the prediction of NAM that there is an effect of density independent of any effect of frequency. Such a test would require the independent manipulation of word frequency and neighbourhood density. Studies using materials designed in this way (i.e. using words with high frequency-high density, high frequency-low density, low frequency-low density, low frequency-high density) seem to confirm the prediction of the NAM that it is neighbourhood density that plays the major role in word recognition with word frequency having a minor role (Bell & Wilson, 2001; Krull, Choi, Kirk, Prusick, & French, 2010).

3.3 Development and Application of the LNT in other languages

As previously discussed, versions of the LNT test have also been developed in other languages such as Cantonese, Mandarin and standard Chinese. The Cantonese LNT (Yuen et al., 2008) and the Mandarin LNT (Wang et al., 2010) were developed using the same process as that used by Kirk et al. (1995) for the English version. Both tests had separate monosyllabic and bisyllabic forms. The Cantonese LNT was evaluated only with hearing-impaired children, while the Mandarin LNT was evaluated with both NH and hearing-impaired children. The results of the two studies were similar and resembled earlier study of Kirk and colleagues in that easy word scores were significantly higher than hard word scores for the bisyllabic words. However, the monosyllable forms of the Cantonese and Mandarin tests showed no effect of lexical properties of word frequency and neighbourhood density for the monosyllabic lists.

According to the authors of both studies, this may be due to the fact that the monosyllabic word lists included numerous homophones when compared to disyllables. In Mandarin and Cantonese, monosyllabic homophones are quite common and include words which have both the same phonemes and the same lexical tone yet have different meanings and different graphemic representations (Taylor & Taylor, 1995). The presence of homophones in these tests poses many challenges in constructing the word lists and interpreting test results. The fact that homophones were considered as neighbours means that the degree of homophony was positively correlated with neighbourhood density. Also, because presentation of the test relied solely on acoustic information, these homophones may have triggered a set of words with diverse lexical properties that did not conform to the definition of easy and hard words. For example homophones may have an identical density but each meaning may have a different frequency so when a child hears a homophone and repeats it correctly they may not be referring to the same meaning that was intended in the test. This further brings into question whether the child was using the lexical properties of density and frequency for word recognition in the same manner as that predicted by the NAM.

A revised standard Chinese Lexical Neighbourhood Test was recently developed excluding homophones from both monosyllabic and disyllabic word lists (Liu et al., 2011). As opposed to previous LNT versions in Cantonese and Mandarin, findings were more consistent with the English test. This implies that the NAM may be applicable to languages with a phonology that is very different to that of English.

3.4 Arabic Lexical Neighbourhood Test

Based on the above information about the English and Chinese LNT, the Arabic Lexical Neighbourhood Test (ALNT) was developed (see chapter two for a full description of the ALNT test development). Because the ALNT test was intended for use with children using CIs, it was essential to explore its suitability for these children prior to using it as a clinical assessment tool. While this is most readily accomplished in NH children, administration of the test to them as it would be used in the clinic would be likely to lead to ceiling performance levels. Here, two alternative approaches to increasing test difficulty were used. Firstly, the difficulty of the test was increased as is common in the validation of audiological speech tests by the addition of speech-like noise (e.g. Kollmeier & Wesselkamp, 1997). A second approach was also employed to more directly approximate the reduced auditory information available to children with CIs; here speech in quiet is presented but after processing through a noise-vocoder simulation of a CI.

3.5 Acoustic Simulations of Cochlear implants

Acoustic simulations of CIs have been widely used with NH subjects to investigate the effects of the loss of spectral and temporal detail that might be expected in CI users. An early study by Shannon et al. (1995) revealed that surprisingly small amounts of temporal and spectral detail could support speech recognition for simple sentences in quiet, for which 3 to 4 spectral channels combined with temporal envelope cues at modulation rates of 16 Hz were sufficient. However, the accurate recognition of more complex materials and speech in noise makes considerably greater demands on spectral resolution (Dorman, Loizou, Fitzke, & Tu, 1998; Faulkner, Rosen, & Wilkinson, 2001).

Many studies have explored speech perception with degraded spectral cues in adults. When it comes to children however, such studies are quite few in number. One study using the English LNT has shown that children's word recognition shows effects of lexical properties with as few as 4 spectral channels (Eisenberg et al., 2002). However, children's performance was only found to reach adult levels of performance with 12 or more channels (Dorman et al., 2000, Eisenberg et al., 2000). This finding that children require more spectral resolution to perform within the adult range may be attributed to their inability to achieve lexical access from spectrally degraded signals as these skills are still maturing (Dorman et al., 2000; Eisenberg et al., 2000).

In addition to investigating the suitability of the test for children using CIs, the current study was intended to examine whether the lexical effects of neighbourhood density and word frequency would be apparent in spectrally degraded speech with our Arabic materials. Because Eisenberg found effects of lexical properties with 4 channels in NH children for English words, and because adult CI users do not receive additional information from more than 6-8 channels (Friesen et al. 2001), it was decided that 4 and 8 channels would be suitable for the age group of children included in this study.

To further test the suitability of these numbers of spectral channels, a pilot study was conducted with 4 NH children with the following numbers of channels: 4, 8, 10, and 12. Each child listened to 50 easy and 50 hard words with one of these four channel numbers. The results of this pilot study showed that scores were near ceiling with 10 and 12 channels. Also, it was important not to have floor effects for the test at the lowest channel used during testing and 4 channels seemed to produce scores that were above floor level.

It was also thought that a doubling of channel number should lead to a substantial increase in spectral resolution that would have an impact on performance, and that it would be valuable to demonstrate that the ALNT was capable of resolving the effects of such an increase of spectral resolution.

3.6 Test-retest reliability

Following principles of psychometric theory, any test that is developed for assessment should be subject to certain standards so that it accurately measures the intended behaviour. One important standard is reliability. Reliability denotes that the test provides consistent results over repeated administrations. Establishing test-retest reliability for speech perception tests is highly recommended as it increases their sensitivity (Mendel, 2008). However, the literature for test-retest reliability for speech perception tests is scarce and there is no agreement on an appropriate time frame between test and retest in the assessment of test-retest reliability. For example, authors of the English LNT (Kirk et al., 1995) used a time frame of between 3 hours to 2 weeks to examine test-retest reliability while authors of the Mandarin LNT and Multisyllabic Lexical Neighbourhood Test MLNT (Wang et al., 2010) used a window of one to two weeks. Within those time frames, high reliability was established for both of the aforementioned tests.

Similar to these studies, the present study investigated the test-retest reliability for the ALNT by administering it twice in noise to NH children. The two test sessions were 2-4 weeks apart. Kirk, Eisenberg, Martinez, and Hay-McCutcheon (1999) found that when they applied the English LNT twice within a time period of 3 hours to 2 weeks, learning effects were apparent on the LNT test only with phoneme scoring rather than word scoring. However, they applied the entire test lists twice to each subject which makes it difficult to distinguish whether these effects were caused by procedural or content learning. Procedural learning implies that improvements in outcome are due to all factors present in the testing situation except those that are related to recall of test words that were administered in a previous session. An example of such factors includes being familiar with the talker's voice (Nygaard & Pisoni, 1998) and noise properties (Theodoridis & Schoeny, 1990). Content learning on the other hand, is caused by memorising the test items from repeated administrations. A recent study by Yund and Woods (2010) that investigated both procedural and content learning in a sentence repetition test showed that procedural learning effects are less pronounced when compared to content learning effects and that content learning effects may persist for up to 3 to 6 months after initial test presentation.

In order to test learning effects in the current study, a method similar to that conducted by Yund & Woods (2010) was adopted where part of the test items were repeated while the rest were unique. This method was used to investigate whether repeating the test words within a short period of time would result in content learning effect, i.e. if repeated items are elevated in the second test while the unrepeated items are not then this is probably an indication of learning effects rather than improvement in speech perception skills. It is important to note that the above study examined learning effects in adults only as opposed to the current study which investigates this phenomenon in young children.

3.7 Main questions for the study

The purpose of this research was to develop a reliable speech perception test that can be used to assess children with cochlear implants. More specifically, the current study aimed at answering the following questions:

1- Can the predictions of the NAM be generalised to Arabic speaking children? This will be evident if our hypothesis that children will perform better on easy words than on hard words is confirmed.

2- Is the test sufficiently sensitive to detect a clinically meaningful effect? Here we assume that the difference between four and eight usable CI electrodes would be clinically significant. Taking NH children listening to vocoded speech as a surrogate for children with CIs, the sensitivity of the test is assessed according to whether it can distinguish between performance with 4 and 8 vocoder channels.

3- Is the test reliable? This is investigated in a test-retest experiment in NH children with speech presented in noise. We hypothesize that children will have similar performance in the first and second session.

3.8 Study 1

The aim of this study was to investigate the feasibility of the newly developed test and explore the effects of lexical properties on word recognition in Arabic speaking children with normal hearing (NH). The scores of each word in the easy and hard lists were used to divide the 50 easy and 50 hard words into two equivalent lists which can be alternately used in future clinical testing to avoid learning effects.

3.8.1 Method

3.8.1.1 Participants

For the first application of the test materials, 39 children aged 5 to 5:11 years were recruited from a kindergarten school in Riyadh, Saudi Arabia. Inclusion criteria were normal hearing, Arabic as the first or only spoken language and the absence of known developmental delays or learning disabilities. Screening for normal hearing was performed with a GSI 66 portable audiometer and required pure tone thresholds of 20 dB HL at 1, 2, and 4 kHz. At 500 Hz a less strict criterion of 25 dB HL was applied because low frequency noise in the testing room may be expected to elevate thresholds at this frequency (Appendix 7.1).

Of the 39 children who were tested, 9 were excluded; of these, 6 were inconsistent in their verbal responses, 1 had unintelligible speech, and 2 failed to complete the test protocol. This resulted in 24 participants, 12 male and 12 female.

3.8.1.2 Test Presentation

The easy and hard words were randomly assigned to four lists of 25 items, each containing a combination of easy and hard words. Stimulus presentation, mixing of speech with noise, and response collection were all performed using a script for MATLAB (Mathworks, Natick MA) that ran on a portable laptop. The stimuli were presented in noise to both ears through Sennheiser HD 25 SP II headphones at 65 dB SPL. The noise was a stationary speech-spectrum shaped noise matching CCITT recommendation G227. A randomly chosen segment of noise from a 6s long sample was selected on each trial. At playback, the noise commenced 300 ms prior to the presentation of the target speech and both speech and noise co-terminated.

3.8.1.3 Test Procedure

Children were tested in a quiet room in their school. The main tests were run at a fixed signal-to-noise ratio (SNR) set individually for each child in order to avoid ceiling and floor effects. The 'intermediate' words were used in a preliminary test to find the SNR using an adaptive 50% correct rule. Speech was set at 65 dB and noise consisted of speech-shaped noise. The mean SNR across subjects was -3.7 dB with a standard deviation of 1.4 dB. For each child, the SNR from the adaptive test was extracted and then manually inserted in the program before running the main test. The presentation order of the 4 lists was counterbalanced across all 24 children and the items within each list were presented in a randomized order. The children were instructed to verbally repeat the words they heard and their responses were audio recorded with a Roland R09-HR digital recorder. Scoring was based on number of words repeated correctly. If the child made a minor misarticulation in producing a word, s/he was asked to describe the word to confirm its identity. All children were rewarded for their participation in the experiment.

3.8.2 Results

3.8.2.1 ALNT Scores

Scores of the 24 children on each test were calculated based on number of words perceived correctly. To test whether the lexical properties of word frequency and neighbourhood density affect speech perception, children's scores on the easy word list were compared to their scores on the hard word list. Since the scores were not normally distributed according to the results of a Shapiro-Wilk test, the Wilcoxon Signed Ranks test was used. This showed that easy words (M= 27.58, SD= 4.71) had a significantly higher score than hard words (M= 20.46, SD= 4.68, with Z=4.12 (p <0.01). The performance of children on easy and hard words is shown in Figure 3.1. Inspection of individual scores for each child however revealed that 2 children scored higher on the hard words than on the easy words by one word. One child scored 25 out of 50 on the hard words and 24 out of 50 on the easy words while the other child scored 29 out of 50 on the hard words and 28 out of 50 on the easy words.

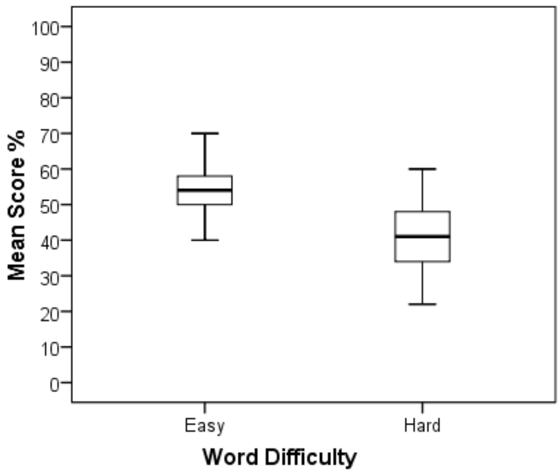


Figure 3.1: Percent correct scores for easy and hard words based on number of words correct out of 50. The box shows the inter-quartile range and the bar represents the median score. Whiskers indicate the range excluding outliers.

3.8.2.2 Establishing two lists with equal difficulty

Clinical use of the test requires a pair of easy and hard lists that are matched for difficulty. This allows control over learning effects that may affect performance if the child is repeatedly presented with the same words. To create the equally difficult lists, for each individual word, the number of children who repeated the word correctly was counted. The words were then equally split into two lists based on matching the number of correct answers for each word (Appendix 7.5).

Children's scores on each of the two easy and two hard lists were further tested for normality using the Shapiro-Wilk test, and in no case was there a significant deviation from normality (Figure 3.2).

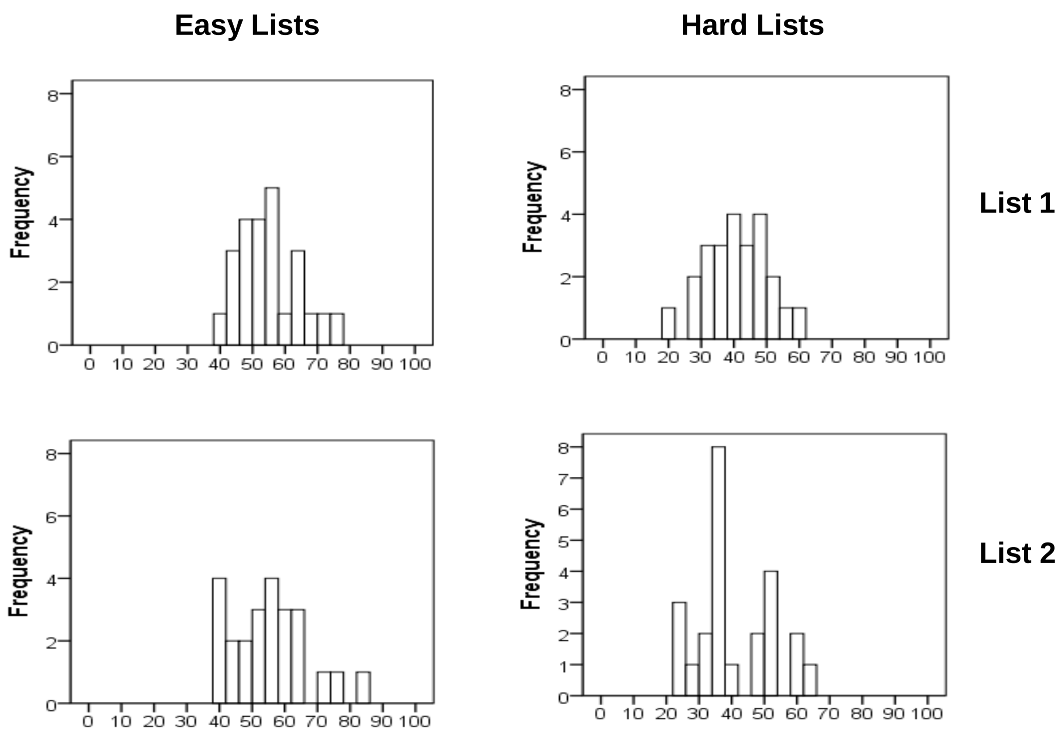


Figure 3.2: Histograms of scores on easy list 1, easy list 2, hard list 1, and hard list 2.

3.8.3 Summary

In this study we examined the effects of neighbourhood density and word frequency on word recognition in Arabic speaking children with NH. Findings of this study demonstrated that neighbourhood density and word frequency significantly affected word recognition in Arabic speaking children and that their performance was thus consistent with the predictions of the NAM. Additionally we were able to select words to make up two easy and two hard lists each of equal difficulty that can be used alternately during clinical testing to reduce learning effects.

3.9 Study 2

In this study we compared the performance of NH children on the ALNT using vocoder simulations of a CI with 4 and 8 channels. This was intended to verify that the difficulty of the test was likely to be appropriate for children with CIs and that the test was sensitive to a difference that would be expected to be of clinical significance. In addition, the study allows a check that lexical properties have similar effects on word recognition between speech in noise and spectrally-degraded speech in quiet.

3.9.1 Method

3.9.1.1 Participants

Twenty eight children aged 5 to 5.11 years were recruited for this study from a kindergarten school in Riyadh, Saudi Arabia. Four of these children were excluded: 1 for providing inconsistent responses, 1 for not completing the test protocol, 1 for having unintelligible speech, and 1 who inadvertently was presented with more practice words than the remaining participants (i.e. more than 10 words). This left 24 children of whom 12 were males and 12 were females. Selection criteria and hearing screening were as in Study 1.

3.9.1.2 Test Stimuli and Presentation

The two easy lists and two hard lists constructed from the results of Study 1 were used in this experiment. Each list contained 25 items. The words were presented without added noise to both ears through Sennheiser HD 25 SP II headphones at a fixed sound level (65 dB SPL) that was comfortable to all listeners.

3.9.1.3 Vocoder processing

Two vocoder conditions were used for presenting the stimuli; 4 and 8 channels. The processing used for vocoding words was similar to that described by Shannon et al. (1995). The signal was band-pass filtered using Butterworth filters with 3 orders per side and frequency-band cut-offs as displayed in Table 3.1. Within each channel, the envelope was extracted by half-wave rectification followed by low-pass filtering at 400 Hz with a 2nd order

Butterworth filter. The envelope was then used to modulate an independent white noise carrier within each channel. The envelope-modulated noise was then band-pass filtered with a filter matching the corresponding channel analysis filter. Finally the band-pass filtered and modulated noise carriers were summed together.

Table 3.1: Lower and upper cut-off frequencies for the 4 and 8 channel vocoders.

	4-Channel Vocoder		8-Channel Vocoder	
Channel	Lower cut-off (Hz)	Upper cut-off (Hz)	Lower cut-off (Hz)	Upper cut-off (Hz)
1	200	543	200	343
2	543	1208	343	543
3	1208	2499	543	821
4	2499	5000	821	1208
5			1208	1748
6			1748	2499
7			2499	3544
8			3544	5000

3.9.1.4 Procedure

Testing was conducted individually in a quiet room at the kindergarten school. Each child listened to 10 ‘intermediate’ words presented through the 8 channel vocoder with feedback from the tester to acquaint them with the sounds they were going to hear before beginning the main test. In the main test, each child was presented with one easy list and one hard list through the 4 channel vocoder, and the other easy and hard list through the 8 channel-vocoder. The presentation of the lists and vocoder conditions was counterbalanced across all 24 children. Additionally, the items within each list were presented in a fresh random order for each test presentation. As before, the children were instructed to verbally repeat the words they heard and their responses were audio recorded. Scoring and rewards to participants were also as in Study 1.

3.9.2 Results

3.9.2.1 Lexical and channel number effects

According to the Shapiro-Wilk test, the data was normally distributed. A two-way repeated measures Analysis of Variance (ANOVA) showed that performance was higher for 8 than for 4 vocoder channels [$F(1,23) = 146.25$, $p<0.01$]. The easy lists also yielded higher scores than the hard lists [$F(1,23)=25.6$, $p<0.01$] overall. The interaction between these two factors was not significant (Figure 3.3).

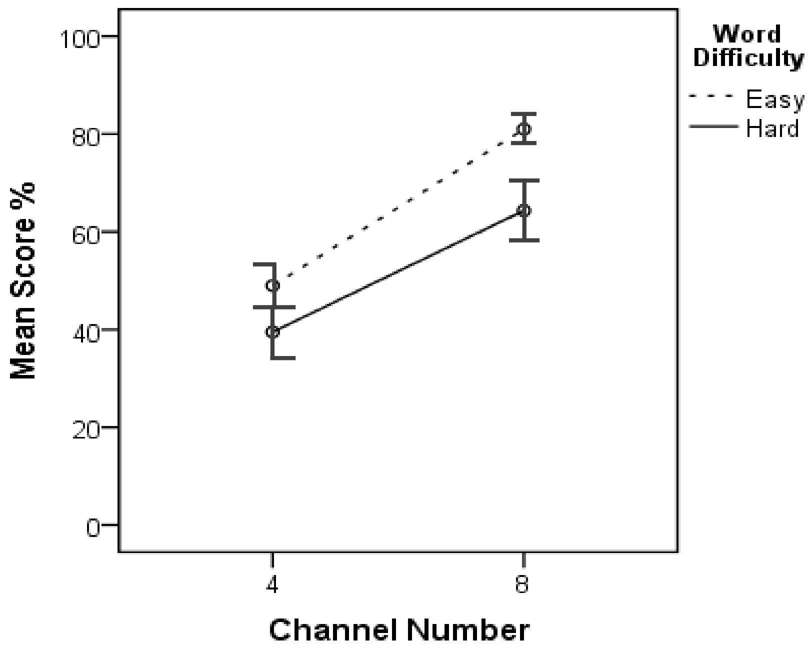


Figure 3.3: Percent scores correct for easy and hard lists with 4 and 8 channel vocoder processing. The maximum possible score is 25, and error bars represent 95% confidence intervals.

3.9.2.2 Multiple Regression Analysis for Lexical factors Affecting Word Recognition

A multiple regression analysis was conducted to investigate which of the lexical factors (word frequency or neighbourhood density) influenced the difference between the easy and hard word scores. Neighbourhood density was not a significant predictor by itself [R^2 = 0.011, $F(1, 1.97) = 1.07$, p=0.30] nor were either neighbourhood density or word frequency when both were included in the regression model [R^2 = 0.04, $F(2,96) = 2.03$, p=0.13]. However, when word frequency was examined alone it turned out to be a significant predictor of ALNT scores [R^2 = 0.041, $F(1,97) = 4.10$, p=0.04] indicating that it explained 4.1% of the variance. The proportion of variance explained however is quite low, and this suggests that word frequency has only a very weak effect on word recognition. These results are further supported by the scatter plots in Figure 3.4 and Figure 3.5. It can be observed from the graphs that children's scores are reaching 100% regardless of neighbourhood density or word frequency.

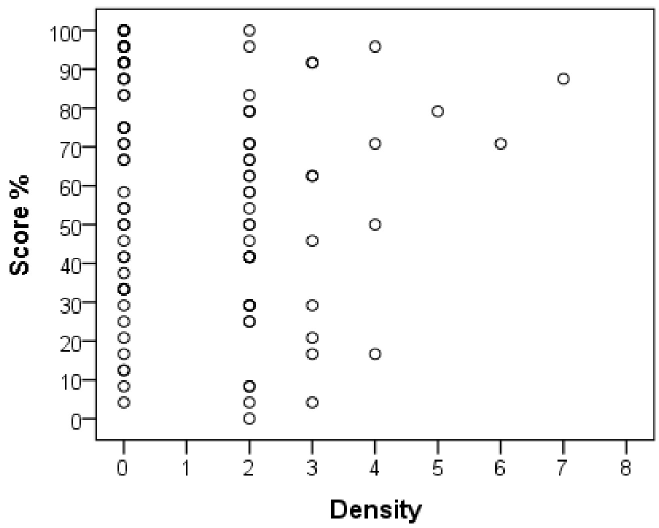


Figure 3.4: Scatter plot showing the correlation between neighbourhood density of the test words and the normal hearing children's scores for those words in vocoded speech conditions simulating a cochlear implant.

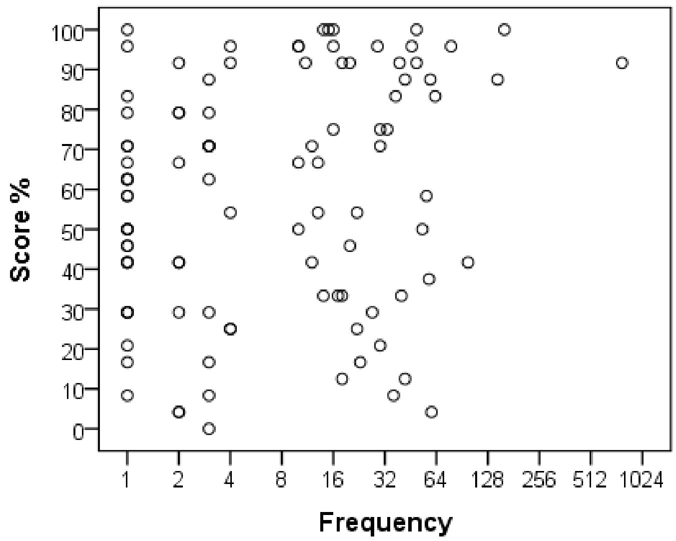


Figure 3.5: Scatter plot showing the correlation between word frequency of the test words and the normal hearing children's scores for those words in vocoded speech conditions simulating a cochlear implant.

In the above analysis the word scores were averaged across the 4 and 8 channel conditions because the lists that were given in each condition were different. Given that children were reaching 100% on some hard words in the 8 channel condition, another multiple regression analysis was conducted including only the 50 words that were presented in the 4 channel number condition to test whether lexical effects were evident when ceiling effects were not present. Results revealed that for the 4 channel condition alone, it remained the case that neither of the lexical factors of neighbourhood density or word frequency contributed to scores on the ALNT when combined [$R^2 = 0.051$, $F(2, 47) = 1.27$, $p=0.28$]. Also, neighbourhood density did not have an independent effect on word scores [$R^2 = 0.05$, $F(1,48) = 2.53$, $p=0.11$] nor did word frequency [$R^2 = 0.019$, $F(1,48) = 0.92$, $p=0.34$].

3.9.2.3 Analysis of neighbour and non-neighbour errors

Analysis was conducted for the type of errors that were produced by the 24 children for each word. A neighbour error was defined as a word that differed from the target or test word by adding, substituting or omitting a single phoneme. A non-neighbour error however was defined as a word that differed from the target word by more than one phoneme. Examination of these errors was conducted by inspecting the phonetic transcriptions of all the errors produced by the children for each of the test words. Separate counts were made for the neighbour errors and the non-neighbour errors across all test words for all children.

For the easy words, 6 out of the 50 words had neighbour error counts that exceeded the non-neighbour error count. For the hard words, 16 of the 50 words had neighbour error counts that exceeded the number of non-neighbour errors while for the remaining words; the number of non-neighbour errors was either equal to or higher than the neighbour errors.

A Chi-square analysis revealed that there was a significant difference between the type of errors produced for easy and hard words: ($\chi 2$ = 35.42, df= 1, p<.001). For the easy words, inspection of the observed and expected proportions revealed that the neighbour error count was lower than the count of non-neighbour errors while the opposite pattern was observed in the hard word error scores.

Figure **3.6** shows the percentages of neighbour and non-neighbour errors for easy and hard words.

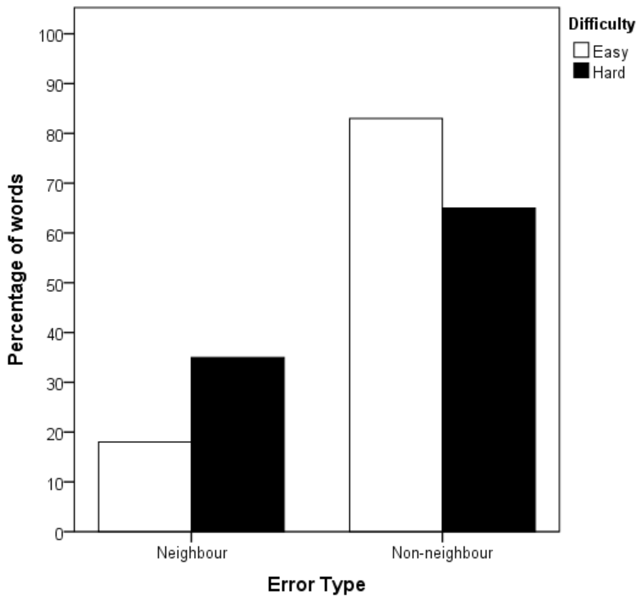


Figure 3.6: Percentage of words that are neighbour errors and words that are non-neighbour errors for both easy and hard words.

3.9.3 Summary

This study explored the effects of two degrees of spectral degradation in noise vocoder processing on word recognition in NH children. Results demonstrated that an increase in the number of channels from 4 to 8 led to a significant improvement in performance on the ALNT. Moreover, children's performance on easy words was significantly higher than their performance on hard words indicating that lexical properties have a similar effect on word recognition under spectrally-degraded conditions as for speech in noise. These results imply that the difficulty level of the ALNT is suitable for children with CIs.

3.9.4 Study 3

The aim of this study was to investigate the test-retest reliability of the ALNT for NH children when speech is presented in noise. Another aim was to determine whether a learning effect occurs from repeated application of the test within a short period of time.

3.9.5 Method

3.9.5.1 Participants

Forty-five children took part in this study (23 males, 22 females). Their ages ranged from 5 to 5.11 years. All children were recruited from a kindergarten school in Riyadh, Saudi Arabia. Selection criteria and screening were as in Study 1.

3.9.5.2 Test Stimuli and Presentation

In order to examine the effect of repeating items, 18 of the 50 easy words and 18 of the 50 hard words were presented in both the first and the second session, while the remaining 32 words from the easy and hard sets were presented only once, in either the first or the second session. To achieve this, each set of 50 words was split into 3 sub-lists of 16 (a, b and c) based on the correct scores for each word in study 1. Each word in each list was matched for the correct number of scores. Sub-lists a and b were presented in the first session and sub-lists b and c in the second session. The two words that remained after the formation of 3 sub-lists of 16 words were presented in both sessions so that all 50 words were included. Six counterbalanced presentation orders for individual subjects were prepared which also varied the sub-list that was repeated. These orders were then repeated as needed across participant group. Appendix 7.6 shows the design for test presentation.

The time interval between the sessions ranged from 2 – 4 weeks in order to ensure that the period between sessions is not too short that the children will remember the test items or too long whereby improvement would be due to developmental factors. For example, Kirk et al. (1999) demonstrated learning effects when the period between two testing sessions was 2 weeks or less only for phonemes but not for words.

As in Study 1, stimuli were presented in speech-spectrum shaped noise to both ears from custom software through Sennheiser HD 25 SP II headphones.

3.9.5.3 Procedure

Children were tested in a quiet room. Similar to Study 1, The main tests were run at a fixed signal-to-noise ratio (SNR) set individually for each child in order to avoid ceiling and floor effects. The ‘intermediate’ words were used in a preliminary test to find the SNR using an adaptive 50% correct rule. Speech was set at 65 dB and noise consisted of speech spectrum shaped noise. The mean SNR ratio across subjects was similar to that used in study 1 and was -4.0 dB with a standard deviation of 1.3 dB. For each child, the SNR from the adaptive test was extracted and then manually inserted in the program before running the main test. On each session, each child was presented with 34 easy words and 34 hard words, all were presented in a random order. Instructions and scoring were as before.

3.9.6 Results

3.9.6.1 Test-retest reliability

To determine test-retest reliability, Pearson product moment correlations were calculated between the scores on the first and second sessions. The correlations were computed separately for the easy and hard word lists. Results revealed that the correlations were highly significant regardless of the list presented. For the easy words: r=0.721, p<0.01. Similarly, for the hard words: r=0.590, p<0.01. In addition to these correlations, reliability was further tested by calculating the within-subject standard deviation (σω) described by Bland and Altman (1996) and Lovett, Summerfield, and Vickers (2013). This within-subject standard deviation can be used to calculate confidence intervals around a single score as well as calculating repeatability. Repeatability specifies the minimum value of the significant difference between scores. The within-subject standard deviations for the easy and hard words were 2.05 and 2.53 words respectively. Repeatability scores were 5.68 for the easy words and 7.01 for the hard words. Absolute differences between scores from the first session and the second session were, as would be expected, very similar to the within-subject standard deviations, being 2 words out of 34 for the easy words (5.8%) and 3 out of 34 for the hard words (8.8%). These differences between sessions were within the expected binomial variability of the score for 43 of the 45 children for both the easy words and the hard words (Figure 3.7 and Figure 3.8).

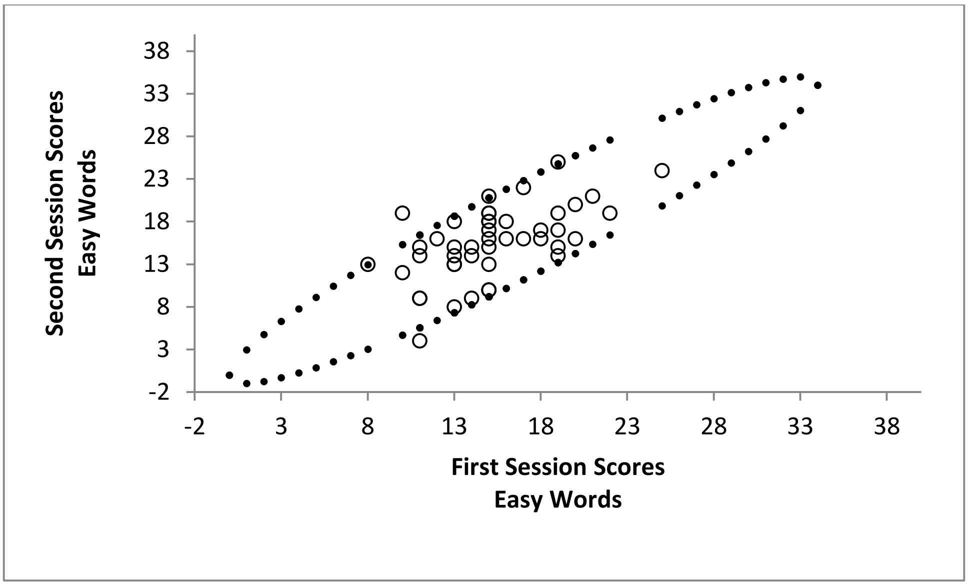


Figure 3.7: Scatter plot showing the correlation between the normal hearing children's easy scores in the first and second session. The filled circles represent the individual confidence intervals.

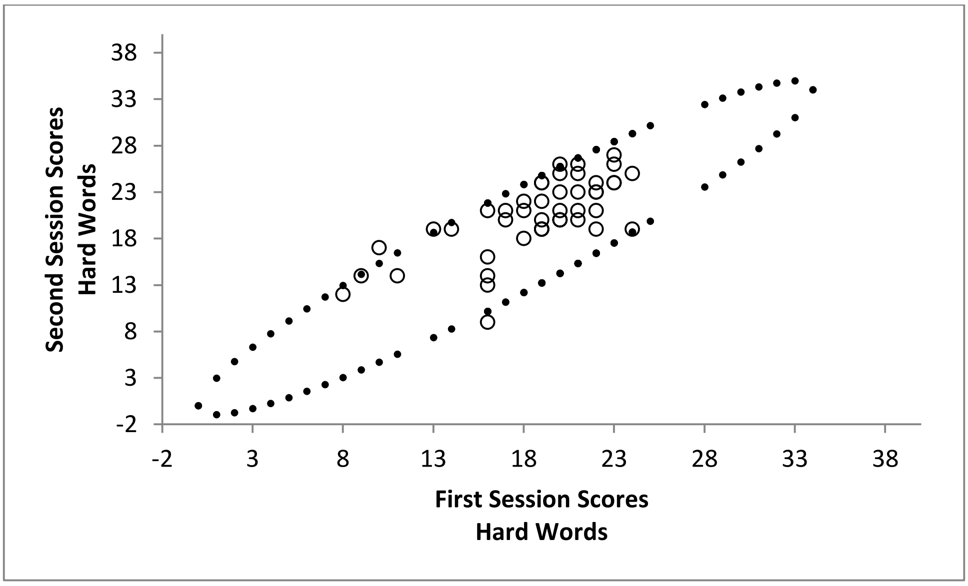


Figure 3.8: Scatter plot showing the correlation between the normal hearing children's hard word scores in the first and second session. The filled circles represent the individual confidence intervals.

3.9.6.2 Effect of lexical factors

In order to find out whether the difference in scores between the easy and hard lists was significant, a two-way repeated-measures analysis of variance (ANOVA) was performed with factors of list difficulty and session. Results showed that the performance on the easy words was significantly higher than that on the hard words [$F(1,44) = 229.37$, $p<0.01$]. As expected from the small differences for individuals over test administrations, there was no significant difference in performance between the first and second session [$F(1,44) = 1.90$, $p=.174$], nor was there any interaction between the two factors (Figure 3.9).

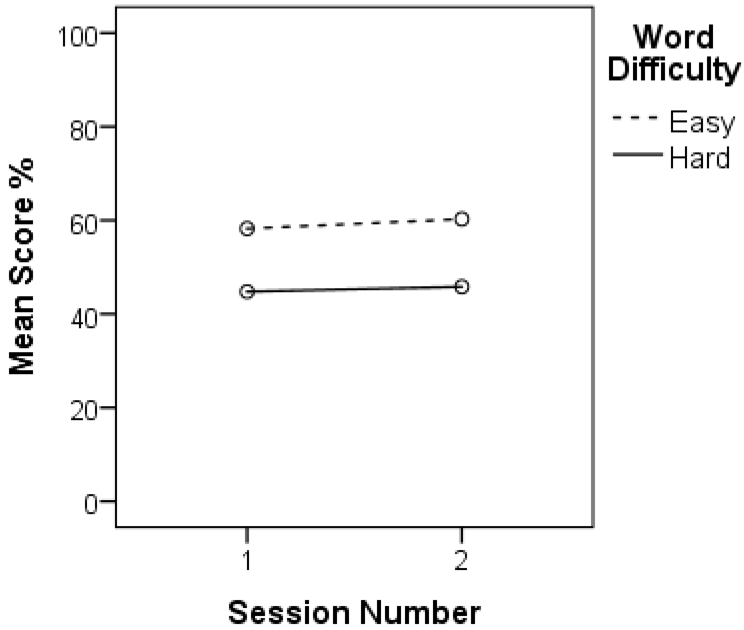


Figure 3.9: Percent scores correct for easy and hard lists in the first and second sessions, the maximum score is 34 for each session.

3.9.6.3 Effects of repeated administration of test items

To investigate if a learning effect occurred for the repeated words in the second session, a 2-way repeated measures ANOVA was performed on the difference in scores between sessions with list difficulty and repetition as factors. The difference in scores was significantly higher for the repeated words [$F(1,44) = 14.721$, $p<0.01$], with no interaction between repetition and list difficulty, indicating that a learning effect indeed took place for the repeated words, and that the time interval of 2-4 weeks between the two testing sessions was short enough for this effect to remain evident (Figure 3.10).

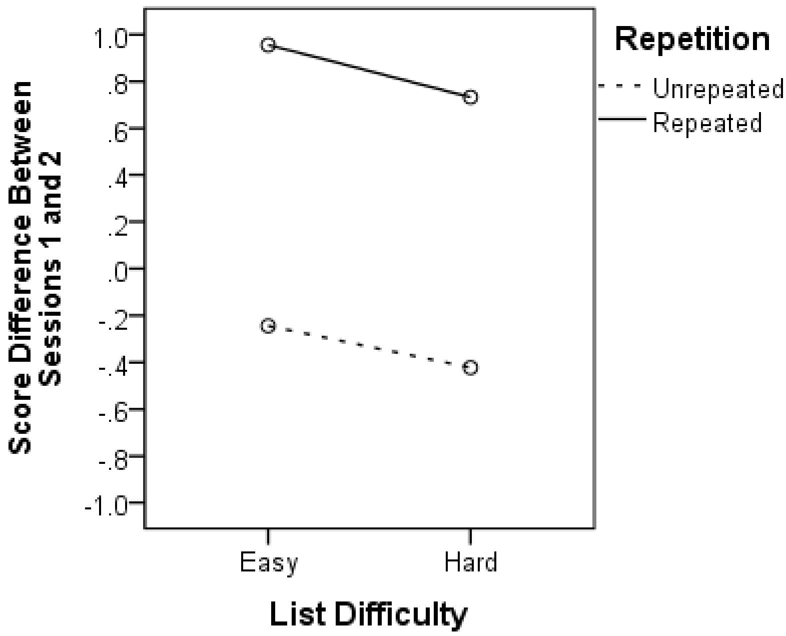


Figure 3.10: Difference scores of sessions 1 and 2 for repeated and unrepeated words for easy and hard lists.

3.9.7 Summary

In this study we studied the test-retest reliability of the ALNT. Results of this study revealed that there was no difference in performance between the first and second sessions, that scores were highly correlated between the first and second test administration, and that the within-subject standard deviation was within the bounds of random variability. These outcomes indicate that the ALNT is a reliable measure for speech perception skills. Nevertheless, children's performance improved significantly in the second session for the repeated words only. This suggests that when the test is used clinically to assess children with hearing impairment, caution should be taken in interpreting results so as not to confuse true change in speech perception skills with that of practice effects if the same test lists were used repeatedly. In order to minimize these practice/learning effects it would be safer to use different word lists on each testing occasion and not to use the same word lists repeatedly within a short time frame.

3.9.8 Study 1 & 3: Multiple Regression Analysis for Lexical factors Affecting Word Recognition

To explore which of the lexical properties (word frequency and neighbourhood density) contributed to the significant difference in scores between the easy and hard words, a multiple regression analysis was performed. The analysis included the scores of all the speech in noise data from NH children across the first and third study (from 69 children). A hierarchical regression method (in SPSS) was used to enter the predictors into the analysis. Neighbourhood density was entered first followed by word frequency. Before conducting the regression analysis, one outlying frequency value was removed but results were not significantly affected by its removal as there was no difference between the results statistically with and without the outlier. Neighbourhood density was a significant predictor of word recognition [$R^2 = 0.066$, $F(1,97) = 6.88$, $p=0.01$] indicating that it explained 6.6% of the variance. Also, when combined together, neighbourhood density and word frequency were significant predictors of word recognition [$R^2 = 0.068$, $F(2,96) = 3.48$, $p=0.03$] thereby explaining 6.8% of the variance (Figure 3.11). However, neighbourhood density and word frequency were significantly inter-correlated in this set of words [$r = -.52$, $p<.001$] and their effects may thus be hard to distinguish from each other. To check that word frequency was not associated with difficulty of recognition, a second regression analysis was therefore performed in which word frequency was entered alone. The results indicated that word frequency did not correlate significantly with word recognition [R^2 = 0.028, $F(1,97)$ = 2.76, p=0.10] (Figure 3.12). Thus, neighbourhood density significantly predicted scores on the easy and hard word lists whereas word frequency did not. However, the proportion of variance explained is quite low, and this suggests that neighbourhood density has only a very weak effect on word recognition for Arabic children.

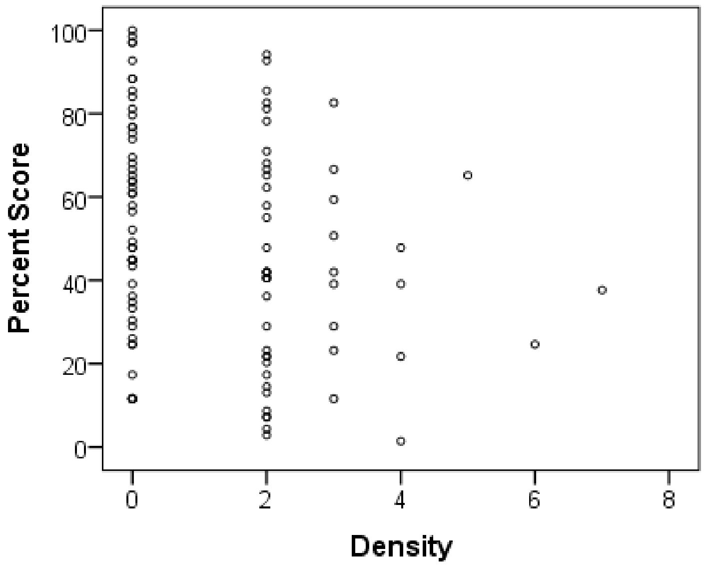


Figure 3.11: Scatter plot showing the correlation between neighbourhood density of the test words and the normal hearing children's scores for those words in noise.

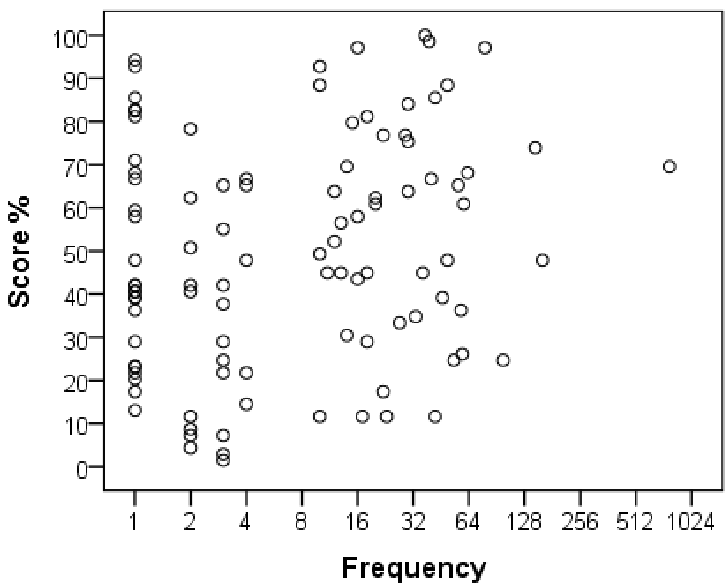


Figure 3.12: Scatter plot showing the correlation between word frequency of the test words and the normal hearing children's scores for those words in noise.

3.9.9 Analysis of neighbour and non-neighbour errors

Analysis was conducted for the type of errors that were produced for each word by the 69 children from the first and the third study.

For the easy words, none of the words had neighbour error counts that exceeded the non-neighbour error count. For the hard words, 14 of the 50 words had neighbour error counts that exceeded the number of non-neighbour errors while for the remaining words; the number of non-neighbour errors was higher than the neighbour errors.

As with the CI simulation study (Study 2), Chi-square analysis revealed that there was a significant difference between type of errors produced for easy and hard words: ($\chi 2$ = 444.271, df= 1, p<.01). For the easy words, inspection of the observed and expected proportions revealed that the neighbour error count was lower than expected while the non-neighbour error count was higher than expected while the opposite pattern was observed in the hard word error scores (Figure 3.13).

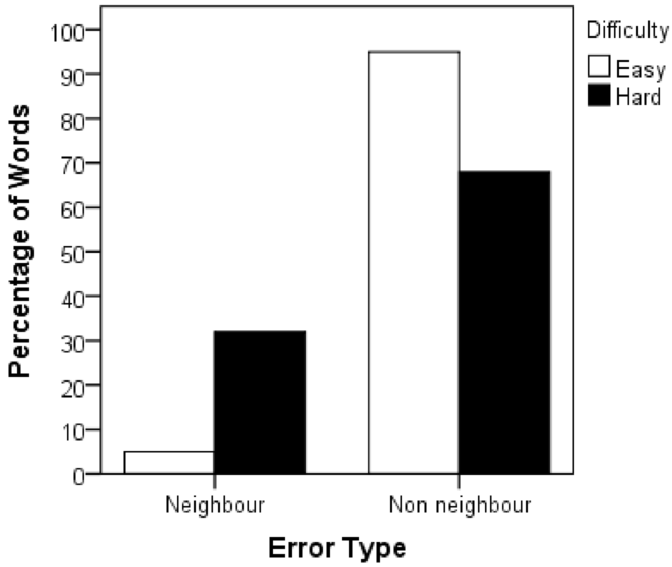


Figure 3.13: Percentage of words that are neighbour errors and words that are non-neighbour errors for both easy and hard words.

3.10 Discussion

The aim of the first experiment was to explore the effects of lexical properties on word recognition in normal hearing (NH) children and to develop two equivalent easy lists and two equivalent hard lists. Results of this experiment revealed that easy words were identified with greater accuracy than hard words implying that the lexical properties of neighbourhood density and word frequency when co-varied do have an effect on word recognition. However the difference in scores between the two word lists was fairly small (14%).

This evidence for lexical effects on word perception further supports the Neighbourhood Activation Model (NAM) (but only weakly) and suggests that like English-speaking children, Arabic children may organize and recognize words in the mental lexicon on the basis of similarity neighbourhoods. These findings extend previous research which has also demonstrated significant lexical effects for lexically-controlled words (i.e., words with high frequency and low density as well as words with the opposite definition) in both NH children (Liu et al., 2011; Wang, Wu, & Kirk, 2010) and children with cochlear implants (CIs) (Kirk, 1998; Kirk et al., 1995; Yuen et al., 2008) whereby words with sparse neighbourhoods were more easily identified than words with dense neighbourhoods.

It is possible that the structure or the content of the mental lexicon may be somewhat different between NH children and children with CIs, which may lead to somewhat different patterns of performance between these two populations even after difficulty levels are made similar through the addition of noise or the use of vocoding in testing with NH children. Therefore, our findings may only be comparable to the results of the Mandarin (Wang et al., 2010) and standard Chinese LNT (Liu et al., 2011) which included a similar age group of NH children.

Indeed, there has been much debate as to whether young NH children use a more holistic approach to recognize words (Charles-luce & Luce, 1990, 1995) or whether they use fine-grained acoustic phonetic information (Dollaghan, 1994). A recent study by Coady and Aslin (2003) compared neighbourhood density of children's and adult's lexicons to address this question. In order to control for differences in vocabulary size between the two groups, for each group, they calculated neighbourhood density as a proportion of the size of the entire lexicon; an approach that had not been used in previous studies. The ratio of the number of neighbours to the number of all monosyllabic words considered in the neighbourhood analysis was calculated for each word in both the children and adult corpora. First, ratios for the words in the children's lexicons were calculated based on each lexicon individually. Second, the ratios for each of the words in the child lexicons were calculated based on the entire adult lexicon. Then the ratios obtained from the two analyses were compared. Their results demonstrated that children's lexicons, especially those of children aged 5 years and younger, are dense and contain many words that are confusable with other words.

Furthermore, they stated that the proportional neighbourhood density was higher in children's than in adult's lexicons and that children's early vocabulary seems to be drawn from words that have high neighbourhood density in the adult lexicon. Although Coady and Aslin (2003) show that children require a certain amount of sensitivity to phonetic detail in order to discriminate between similar words, they argued that this does not preclude the use of a holistic method in discrimination. Still, this does not imply that children use phonemic units in word recognition but it may suggest that children use different methods in recognizing words depending on the context in which words are heard.

The findings of the above studies along with other studies suggest that having denser neighbourhoods early in life does not only assist speech perception but also facilitates acquisition of novel words that are phonetically similar to known words (Gierut & Morrisette, 1998; Hollich et al., 2000; Storkel, 2004). Thus, dense neighbourhoods at an early stage seem to play an essential role in vocabulary growth.

There is always likely to be variability between the vocabularies of young children. Such variability may explain why two of the children in this sample differed from their peers in scoring higher on the hard than on the easy word list, and also that one child scored equally on both lists. These children may not have learned so many neighbours as their peers for some of the hard words, and as a result, neighbourhood density and word frequency may have been inappropriately defined for those children. Another explanation is that these children may have not yet established lexical representations (i.e. association of acoustic phonetic patterns to their meanings) for some of the words in the hard lists. The low frequencies of the hard words mean that children will rarely be exposed to them. Consequently, their performance may have been influenced by phonotactic probability rather than neighbourhood density. Other explanations include: fatigue, differences in motivation and alertness which may have had adverse effects on their scores.

Another aim of the first experiment was to develop two equivalent easy lists and two equivalent hard lists for use alternately to avoid learning effects (Kirk et al., 1999). This was achieved by assigning the words to different lists based on the number of children who scored correctly on each word.

The second experiment administered the ALNT under spectrally-degraded conditions through the use of a 4 channel and an 8 channel vocoder with NH children. Children scored better with 8 than 4 channels which confirmed that the test was able to detect what would be thought of as a clinically meaningful difference in both an individual and a group analysis. The effects of channel number are consistent with previous findings (Eisenberg et al., 2000; Dorman et al., 2000) which show that children have difficulty recognizing words that are processed through a small number of channels i.e., 6 or less. The findings of Study 2 also indicate that the difficulty of the ALNT materials is likely to be appropriate for children with CIs, given that adult CI users seem unable to use more than 6-8 channels of spectral information even when there are 22 active electrodes (Friesen et al. 2001). Eisenberg et al. (2000) also reported that young children's (5-7 years) speech perception skills are still maturing and that they may require several years to reach adult performance on spectrally degraded speech. When applying this information to children with CIs, it seems that the limited spectral resolution is likely to hinder the maturation of speech perception development in these children in ways that are different from and not observable in children with NH. When relating the results of the NH children in Study 2 to performance of actual CI children it would be expected that NH children may perform more poorly than CI children, especially given that the NH children in current study have not had experience in listening to spectrally degraded speech as opposed to children with CIs. Eisenberg et al's study (2002) confirmed this when they compared the performance of NH children through 4 channels to that of CI children. NH children's performance was 20-30% poorer than children using CIs.

The other aim of this experiment was to discover whether lexical properties have a similar impact on speech perception under spectrally-degraded conditions as for speech in noise. It might further be predicted that effects of neighbourhood density would be modulated by spectral resolution given that poor spectral resolution may prevent access to some phoneme contrasts making some neighbours perceptually equivalent to each other. However, the findings of this experiment show comparable differences between easy words and hard words for the 4 channel and 8 channel vocoders, implying that at least this degree of difference in spectral resolution does not lead to a substantial change in neighbourhood density effects. The present findings are also in line with a previous study by Eisenberg et al. (2002) who tested children between ages 5 and 14 years on lexically-controlled words and sentences under spectrally degraded conditions.

Although the definition used for identifying neighbours of target words may be considered simplistic in that it does not consider a metric relationship among the features of phonemes that are present in the target word and those that are substituted, omitted, or added to form word neighbours nor the quantity of phonemes that may differ to form neighbours (Bailey & Hahn, 2005; Gallagher & Graff, 2012; Ussishkin & Wedel, 2002), it still seems robust enough to produce such an effect in the current study as well as in previous studies.

The third study investigated the test-retest reliability of the ALNT by presenting the test on two occasions to NH children in noise. The two sessions were set 2-4 weeks apart. Pearson product moment correlations revealed significant correlations in children’s performance between the first and second sessions for both easy and hard words. Also, both the average differences and the within-subject standard deviations of scores between the two sessions were within the range of random variation at 2 and 3 words per list. These outcomes indicate that the ALNT test is very reliable. Two additional ANOVA’s were conducted on the same data. The first was a two-way repeated-measures ANOVA to determine whether lexical properties continue to have an effect on speech perception performance. Findings replicated those observed in study 1 and 2 where children consistently performed better on easy than on hard words. An analysis of the repeated words showed that word recognition scores significantly improved in the second session thereby confirming the presence of learning effects from repeated administration of the same test words over a short period of time. This implies that alternate lists should be used during clinical testing so that learning effects are not confused with true change in word recognition skills.

In addition to assessing the reliability of the current test, it is equally important to investigate its validity. This could be achieved by comparing performance on the ALNT with other speech and language measures and looking at the degree of correlation between them. Unfortunately there are no standardized speech and language measures in Saudi Arabic for children that could be used in this way. Nevertheless, this could be an important topic for future research as soon as other speech and language assessment tools become available.

The sensitivity of a test is a further important aspect. Here we have shown that the ALNT was able to detect a meaningful difference in scores on 4 and 8 vocoder channels in a group analysis, and thus has useful sensitivity. Similarly, in an individual analysis, when repeatability measures obtained from the test-retest experiment were applied to scores of the second experiment (vocoded speech condition) a meaningful difference was detected in 20 out of 24 children for the easy lists (Figure 3.14) and 12 out of 24 children for the hard list (Figure 3.15). This shows that at an individual level, the easy list seems to be more sensitive to measuring change than the hard list.

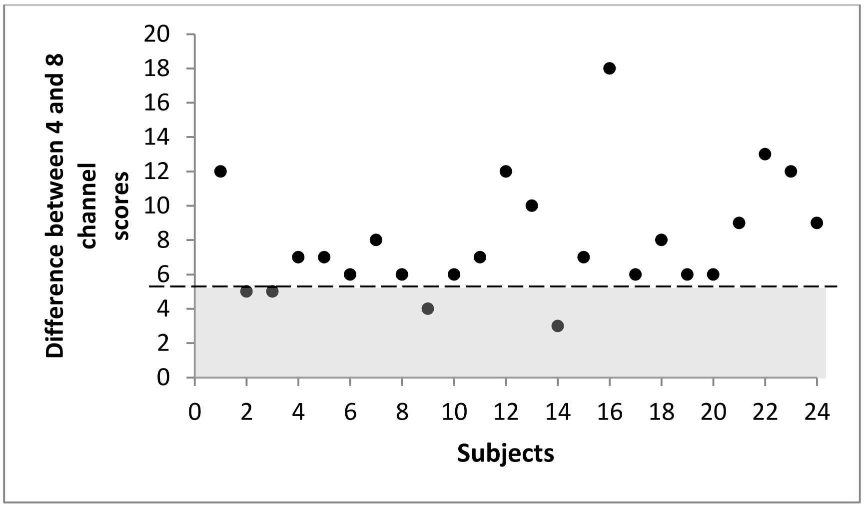


Figure 3.14: Dot plot showing the difference between scores of 4 and 8 channels for the easy words. Each dot represents one child. The dashed line displays the repeatability measure obtained from the test-retest experiment and the shaded area represents the repeatability range.

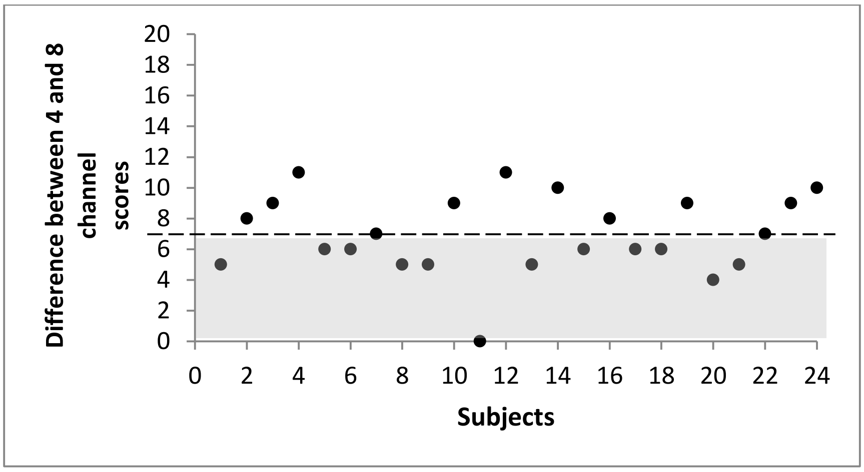


Figure 3.15: Dot plot showing the difference between scores of 4 and 8 channels for the hard words. Each dot represents one child. The dashed line displays the repeatability measure obtained from the test-retest experiment and the shaded area represents the repeatability range.

The designs of the first and third studies have controlled for age, gender, and test condition variables by testing children from one age group (5-5.11 years) with an equal number of males and females in noise conditions. With these factors being controlled, it can be determined whether the neighbourhood density or word frequency accounted for word identification by running a multiple regression analysis. This analysis revealed that word frequency did not play a role in lexical access whereas neighbourhood density did but it only explained a small proportion of the variance. These findings contradict those reported in a previous study where word frequency accounted for approximately 50% of the proportion of variance in Chinese (Liu et al., 2011). Additionally, when neighbourhood density was inspected in Liu and colleagues' study, it was found that it explained approximately 13% and 17% of the variance for monosyllables and disyllables respectively. The different results found in the current study may have been due to the small value range for word frequency compared to that in the Liu and colleagues' study. Their database contained 1979 monosyllables and 2745 disyllables with word frequencies ranging from 1 to 4855 (median = 7) and 1 to 1878 (median = 2) while in the current study, word frequency ranged from 1-779 with a median of 2. Despite this, when a multiple regression analysis was performed on the data from the children in the vocoded speech condition, the findings were different from those in the data from children tested in the noise conditions. In the vocoded speech condition, neighbourhood density did not correlate with ALNT scores, neither did neighbourhood density and frequency when combined together. Word frequency however, did correlate with ALNT scores but the correlation was very weak (i.e. it explained only 4.1% of the variance). One reason for this could be that scores were averaged across the 4 and 8 channel conditions. This was necessary because the lists that were included in the 4 channel number condition were different from those included in the 8 channel number condition. Because the easy and hard words which were given via 8 channels were easier to identify than those in the 4 channel condition, children were able to reach 100% scores even on hard words that were presented via 8 channel numbers. To rule out the impact of ceiling effects in the 8 channel number condition, another multiple regression analysis was performed on the lists that were given in the 4 channel condition only. Findings showed that effects of neighbourhood density and word frequency were still not significant, indicating that the lack of lexical effects is not due to ceiling effects. A second reason for the insignificant correlation may be the reduced spectral cues in the vocoded speech condition; it may well be that their impact on discriminating phonemic features was greater than that of noise because these children had no experience with hearing in spectrally degraded conditions. This may have caused the effect of neighbourhood density to diminish in the vocoded conditions, especially given that this effect was initially very weak in the noise condition.

3.11 Conclusion

The aim of the current study was to examine the performance of 5 year old NH children on the ALNT to establish whether it conforms to the predictions of NAM under spectrally degraded conditions and to investigate its test-retest reliability. This newly developed test was able to detect differences among the two lexically different word lists when used with 5 year old NH children in the presence of background noise and in spectrally degraded speech conditions. Also, results of the experiments of NH children in the noise condition demonstrated that neighbourhood density and word frequency do play a role in speech perception and that these lexical properties may either make a word easier or more difficult to recognise in the Arabic Language. However, the effects of these factors on word recognition in Arabic are quite small when compared to English and Chinese languages. Finally, the ALNT has been shown to be a sensitive measure for evaluating speech perception skills with a high degree of test-retest reliability.

In the following chapter, the ALNT will be used in children with CI in an attempt to examine the efficacy of the ALNT as a clinical assessment tool as well as examining the effect of the lexical factors of word frequency and neighbourhood density on open-set word recognition in these children.

4 Chapter Four: Administration of the Arabic Lexical Neighbourhood Test on children with cochlear implants

4.1 Introduction

Congenital or pre-lingual severe to profound hearing loss in children leads to major delays in the development of communication skills. In cases where hearing aids are not sufficient, cochlear implants (CI) have proven to be successful in providing these children with access to sound.

Research over the past years has demonstrated that some children with CIs have been able to perform at a level similar to their hearing peers on measures of speech and language skills. However, several factors have been identified as related to performance post cochlear implantation. Such factors include age at implantation, mode of communication, presence of residual hearing, duration of hearing loss, nonverbal cognitive abilities, and socioeconomic status.

Age at implantation has been identified as one of the important factors affecting outcome post cochlear implantation. A prerequisite to receiving an implant early in life however, is early identification of hearing loss something which has become possible recently in Saudi Arabia due to the realization of the importance of early newborn hearing screening programs (Afifi & Abdul-Jabbar, 2007). Given that the use of newborn hearing screening in Saudi has been increasing, this will likely lead to more children being implanted earlier in life (Alwan & Zakzouk, 2003; Habib & Abdelgaffar, 2005).

What happens after these children have been implanted? Speech perception is considered the utmost primary outcome after cochlear implantation as it is supposed to facilitate oral speech and language acquisition. And in order to measure performance on speech perception, age-appropriate measures should be readily available for assessing these children. This leads to the primary focus of the current thesis: the development of the ALNT test for Saudi children with CIs. There have been prior attempts to develop speech perception tests for the Saudi population (Alusi, Hinchcliffe, Ingham, Knight, & North, 1974; Ashoor & Prochazka, 1982; Ashoor & Prochazka, 1985). However, they were based on Modern Standard Arabic (MSA) instead of colloquial Arabic, and because MSA is mostly used in educational settings, such a test may not reflect the perceptual skills required in children's daily situations. Therefore, the current study aimed at developing a speech perception test using colloquial vocabulary that would closely simulate the language that they hear in their daily interactions. This was discussed earlier in more detail in Chapter 2.

Various measures of speech perception have been established over the years to suit children with diverse language abilities, skills, and ages. Many studies have linked improvement in speech perception with improvements in other areas of speech and language development such as receptive and expressive language skills, speech production and speech intelligibility. Furthermore, the performance of children with CIs on different speech perception measures has been compared with normal hearing (NH) peers to establish performance baselines.

The present study attempts to investigate the clinical feasibility of the ALNT for children for CIs by applying it three times over a period of 18 months, a period of time over which it might be expected that speech perception improves to a measureable degree (Nasser et al., 2005). The performance of children with CIs, here tested with speech in quiet, will also be compared to that of NH age-matched peers when listening to vocoded speech (See Chapter 3, section 3.9). An additional objective of the current study is to test the predictions of the Neighbourhood Activation Model (NAM) e.i., that the lexical properties of neighbourhood density and word frequency affect speech perception in children using CIs.

4.2 Factors affecting outcome in children with cochlear implants

The cochlear implant program at King Abdulaziz University Hospital, Riyadh, Saudi Arabia has operated with rather strict selection criteria that a child needs to fulfil in order to receive a CI. These criteria were adopted five to six years ago when the availability of CIs was quite limited. In consequence, the group of children in this study, who all received implants from this program, is quite homogenous. This situation has recently changed and due to more CI devices being available, selection criteria are less strict and children with additional disabilities are being implanted.

The following sections define the criteria that have been taken into account for candidacy prior to cochlear implantation for the children who participated in this study.

4.2.1 Communication mode

Communication mode (i.e. the method that the child uses to communicate in daily setting whether it is sign language, oral communication or both methods which is also called total communication) and its association with speech and language outcomes has been repeatedly investigated. However, research results were found to be equivocal. For example, while a number of studies found that oral communication predicted better language skills than signed communication (e.g., Geers, Brenner, & Davidson, 2003; Geers et al., 2002; Geers, 2003; Hyde, Punch, & Grimbeek, 2011; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Wie, Falkenberg, Tvete, & Tomblin, 2007), other researchers found no relationship between communication mode and general expressive and receptive language skills (Dawson, Blarney, Dettman, Barker, & Clark, 1995; Kirk, Pisoni, & Miyamoto, 2000; Robbins, Svirsky, & Kirk, 1997; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). These contradictory results may have been a result of several factors, such as variations in methodology (e.g. sample size, type o assessments used, presence or absence of residual hearing prior to implantation, degree of language development prior to cochlear implantation). When communication mode was correlated with speech perception skills however, it was found that children who were using oral communication significantly outperformed the children who used total communication (Dunn et al., 2014; Sarant, Blamey, Dowell, Clark, & Gibson, 2001; Taitelbaum-Swead et al., 2005). The fact that the children in the current study were all using oral communication eliminates communication mode as a possible factor in this study.

4.2.2 Nonverbal IQ

Nonverbal cognitive ability has been recognized as one of the primary factors affecting language development in children using CIs and accounts for a large proportion of the variance in multiple studies (Dawson, Busby, McKay, & Clark, 2002; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Geers, Nicholas, & Sedey, 2003; Holt & Kirk, 2005; Sarant, Harris, Bennet, & Bant, 2014; Sarant, Hughes, & Blamey, 2010). Non-verbal IQ measures allow assessment of IQ regardless of the child's language level. Therefore, this measure is suitable for children with CIs whose language level may be adversely affected by their hearing loss. Geers et al. (2009) examined the effect of IQ on receptive and expressive language skills and found it to be one of the strongest predictors of language development explaining between 15% and 24% of the variance. However, correlations with speech perception scores were not established as these scores were not included in this study.

Sarant et al. (2010) examined the effect of nonverbal IQ on both expressive and receptive language as well as speech perception skills in preschool and school aged children. Results of this study revealed that cognitive abilities were significantly correlated with outcome on receptive and expressive language measures but not with speech perception measures.

However, they stressed that IQ must have an indirect effect on speech perception tests as they are conducted through a language medium.

Children in the present study all had average or above average IQ as it was a prerequisite for being a candidate for cochlear implantation.

4.2.3 Socioeconomic status

Studies of children with CIs have shown that socioeconomic status has a positive influence on speech and language outcomes with higher socioeconomic status resulting in better speech and language skills (Geers, Nicholas, & Moog, 2007; Geers, Nicholas, et al., 2003; Rowe, Raudenbush, & Goldin-Meadow, 2012).

Niparko et al. (2010), for example, explored expressive and receptive language growth in children who underwent cochlear implantation before the age of 5 years. The children were assessed longitudinally over a 3 year period following cochlear implantation. Results revealed that greater growth in expressive and receptive communication and better speech perception tended to be found in children who had a higher socioeconomic status. Hodges, Ash, Balkany, Schloffman, and Butts (1999), investigated the factors that contributed to speech perception scores in 40 children using CIs. They found that several factors influenced performance on speech perception tasks, one of which was socioeconomic status, where higher socioeconomic status was linked to higher speech perception scores.

The children who participated in the present study mostly came from families of similar socioeconomic status. Socioeconomic status is usually tied with educational status (i.e. the higher the educational level, the better the income). Most of the children in this study have at least one highly educated parent (i.e. Bachelor degree level) as it was essential for the program that parents understand the need of rehabilitation and home training post cochlear implantation and the important role it plays for the child to benefit from a CI.

4.2.4 Pre-implant residual hearing

Speech recognition abilities post cochlear implantation have been found to be associated with better pre-implant residual hearing (Dolan-Ash, Hodges, Butts, & Balkany, 2000; Gantz et al., 2000; Zwolan, Collins, & Wakefield, 1997). Additionally, use of hearing aids by children with residual hearing allows stimulation of the auditory system prior to the receipt of a CI. Experience with hearing aids and access to sound may advantage these children compared to those implanted at the same age but with no residual hearing, as shown for example by the finding that children with more aided residual hearing before implantation show significantly better post-implant spoken language skills, regardless of age at implantation (Nicholas & Geers, 2006; Szagun, 2001). According to Nicholas and Geers (2007), this stresses the importance of early implantation of children without residual hearing or sufficient hearing with hearing aids so that important language acquisition time is not lost.

With a few exceptions, almost all of the children who underwent cochlear implantation and participated in this study had a pre-implant threshold of at least 95 dB or higher bilaterally according to the Auditory Brainstem Response procedure (ABR) indicating that most of them had no residual hearing prior to implantation.

4.2.5 Duration of Implant use

Duration of CI use has been shown to positively correlate with both expressive and receptive language skills and children continue to demonstrate improvements as they grow and their experience with their CI devices increases (Hay-McCutcheon, Kirk, Henning, Gao, & Qi, 2008). Similarly, increased listening experience with CIs has been found to affect speech perception abilities. In a study by Calmels et al. (2004), 63 prelingually deaf children were followed up to five years post implantation. The children were evaluated by the Test for the Evaluation of Voice Perception and Production (TEPP) which includes closed and open set word and sentence perception tests. The median percentages of open-sentence speech perception (OSS) were 8.77% for 3 months post implantation; 16.54% for 1 year post implantation; 34.33% for 2 years post implantation; 58.56% for 3 years post implantation; 68.42% for 4 years post implantation and 76.3% for 5 years post implantation. This improvement was not significant during the first year following implantation but was significant from 1 to 3 years and from 3 to 5 years post implantation. Other studies that have investigated the effect of duration of CI use from 5 to 10 years have also found that performance significantly improves during this period. Beadle et al. (2005) for example followed up 30 children for 10 years post cochlear implantation. The Categories of Auditory Perception Scale was used to rate improvement in speech perception skills. Children's scores improved from a rating of 0 pre-implantation to an average of 6 out of 7 at 5 years post implantation and continued to improve until the mean rating was 7 out of 7 at ten years post implantation. Uziel et al. (2007) also investigated improvement in speech perception skills in French children after 10 years experience with a CI. They used a translated French version of the Phonetically Balanced Kindergarten Test (PBK). Performance on the PBK was reported at 5 and 10 years post implantation and it showed an increase of 7% from 65% at 5 years post implantation to 72% after 10 years post implantation. These longitudinal studies confirm that most children continue to improve in speech perception skills even beyond 5 years of implant use and that their performance does not reach a plateau.

It is clear from the above that children perform differently depending on the extent of their experience with their CI and since children recruited for the current study have variable durations of CI experience this factor will consequently affect performance on the ALNT during testing occasions and may also account for some of the variability in outcome. Therefore, it is essential that this factor be taken into account when analysing the data from the children included in this experiment.

4.2.6 Age at implantation

Prolonged deprivation of sound has serious effects on the developing auditory system (Moore, 1985). Providing children with a cochlear implant (CI) early in life may reduce this impact on the auditory system. Age at implantation has been continuously identified as one of the most important factors pertaining to improvements in expressive and receptive language skills post cochlear implantation (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Duchesne, Sutton, & Bergeron, 2009; Kirk et al., 2002; Nicholas & Geers, 2007; Nikolopoulos, O'Donoghue, & Archbold, 1999; O'Donoghue, Nikolopoulos, & Archbold, 2000; Tajudeen, Waltzman, Jethanamest, & Svirsky, 2010). Children who were implanted at a younger age were also found to have better speech perception skills than children implanted at an older age (Manrique, Cervera-Paz, Huarte, & Molina, 2004). Manrique and colleagues found that children implanted between 0 and 3 years had higher speech perception scores than children implanted between 4 and 6 years of age. Moreover, when duration of implant use was controlled, children implanted before 2 years outperformed children implanted after the age of 2 in speech perception when tested five years post implantation. These results were replicated by Svirsky, Teoh, and Neuburger (2004) who studied speech perception in children implanted at 1, 2, and 3, years of age. Evidence of the influence of age at implantation has resulted in a decrease in the age at which children receive cochlear implants (Tomblin, Barker, & Hubbs, 2007; Valencia, Rimell, Friedman, Oblander, & Helmbrecht, 2008; Wie, 2010). However, not all studies that investigate speech perception relative to age at implantation show this pattern (positive correlation between age at implantation and speech and language skills). For example one recent study shows no significant differences between early and late implanted children when tested at 7, 11, and 13 years post implantation, suggesting that the advantage of early implantation may diminish over time (Dunn et al., 2014). However the speech perception tests used in this study were noted to be relatively easy for these older children and there were ceiling effects for some participants. This might suggest that there remain effects of age at implantation in older children but that these are only be evident when sufficiently difficult tasks are used.

However the fact that children implanted earlier in life perform better than children implanted later suggests that there is an optimal time frame or "sensitive period" for language development (Kral & Sharma, 2012). Evidence from electrophysiological studies has determined age cut-offs for auditory plasticity ranging from 3.5 years to 7 years (Dorman, Sharma, Gilley, Martin, & Roland, 2007; Sharma, Dorman, & Spahr, 2002a; Sharma, Gilley, Dorman, & Baldwin, 2007; Sharma, Nash, & Dorman, 2009). Early implantation therefore, allows taking advantage of this sensitive period and may enable children to develop speech and language skills that approximate those observed in age-matched normal hearing (NH) children. Early implantation not only allows the acquisition of verbal language but it also provides these children with the opportunity to be placed in regular educational settings along with their hearing peers (Geers et al., 2009).

In the current study, most children were implanted before the age of 6 years as age was also a criterion for cochlear implantation. This criterion was based on the fact that implantation during "a sensitive period" is likely to yield better outcomes post cochlear implantation. Sensitive periods have been identified as a timeframe during which neural plasticity is elevated. Neural plasticity is the brain's ability to adjust in response to sensory input and this ability is usually very high during the first few years of life (Huttenlocher & Dabholkar, 1997). The limits of the plasticity of the central auditory system have been examined using cortical auditory evoked potentials (CAEPs). Specifically by examining the P1 latencies of the CAEPs (i.e. the time it takes for the brain to respond to an incoming stimulus). It has been found that P1 latencies decrease as age increases in NH children (Sharma, Dorman, et al., 2002a). Thus, P1 latency has been used as an indicator of auditory cortical maturation.

Research in this area has revealed that cortical response latencies were within normal limits in children who were implanted prior to the age of 3.5 years and were abnormal for children receiving implants after the age of 7 years. Children who were implanted between the ages of 3.5 and 7 years however had variable response latencies. The authors reported that these findings suggest that at the age of 3.5 years the auditory system is highly plastic and that this period of plasticity continues until the age of 7 years after which it is hugely decreased (Sharma & Dorman, 2006; Sharma, Dorman, Spahr, & Todd, 2002; Sharma, Dorman, et al., 2002a; Sharma, Dorman, & Spahr, 2002b).

So far, from this review it can be seen that the children included in the current study form a more or less homogenous group and that the factors outlined above are mostly well controlled. There remain many other possible sources of inter-individual variability and recent studies confirm that this should be expected (Niparko et al., 2010). Sources of individual variability may stem from differences in the survival spiral ganglion cells, differences in electrode locations in relation to remaining neural tissue, and differences in electric stimulation strategies (Dorman et al., 1998). Additional factors that have been recently identified and researched as contributing to this individual variability include attention and working memory. These are discussed in the section below.

4.2.7 Attention

Only a few studies explore the effect of attention in relation to speech perception and language acquisition. Houston, Pisoni, Kirk, Ying, and Miyamoto (2003) measured sustained attention to repetitive sounds compared to silence in children with CIs between 1 day and 1.6 years post cochlear implantation. A modified version of the Visual Habituation Procedure (VHP) was used to measure sustained attention. The idea behind the VHP is that “that infants will attend longer to a simple visual display if what they are hearing is interesting to them (i.e., it captures their attention)". In this experiment the infant sat on a caregiver's lap in front of a TV screen. Infants' sustained attention was measured for two types of trials: 1) checker board pattern without any accompanying sound and 2) checker board pattern with repeating speech sounds. There were also two types of repeating sounds: a 4 s continuous ('ahh') versus a discontinuous CVC pattern ('hop hop hop') and a 4 s /i/ with a rising intonation versus repetitions of a 4 s /i/ with a falling intonation. The experiment consisted of two phases, a habituation phase and a test phase. In the habituation phase sound trials were compared to silent trials until the child's attention decreased and reached habituation. Once the habituation phase was complete, a test trial began. In the test trial, sounds in the habituation phase were compared to a novel sound. Results revealed that the 6 month old NH children demonstrated greater looking time preference for sound versus silence than did deaf children who had used their implants for duration of 6 months suggesting that in children with CIs, attention to speech is reduced compared to their NH peers. Moreover, both groups of children attended significantly longer to the novel sounds trial than the old sound trials suggesting that they were able to discriminate the speech patterns. A follow-up experiment that included children implanted between 13 and 30 months of age found that by this age attention to speech was more similar to hearing age-matched peers (Houston, 2009). The author reported that infants' reduced attention to speech may hinder speech and language development, and noted that infants' attention to speech at six months of age was correlated with their speech perception scores two to three years later. However, according to Houston and Bergeson (2014), these findings demonstrate that deaf children with CIs do not attend to speech in the same way as NH children, and that it is important to understand the factors that may improve deaf children's attention to speech and potentially enhance their language development.

According to Jusczyk, Cutler, and Redanz (1993) and Jusczyk and Hohne (1997) attention to speech is important for encoding representations into memory, which is considered next.

4.2.8 Memory

Explanation for the variability seen in children with CIs has been related to differences in cognitive functions, one of which is working memory. Pisoni has repeatedly argued that this variability will only be understood if interactions between spoken language and cognitive functions are considered (Pisoni, 2000; Pisoni & Cleary, 2003; Pisoni, Kronenberger, Roman, & Geers, 2011). This has been supported by a study conducted by Pisoni and Geers (2000) who found correlation coefficients ranging from 0.52 to 0.71 between digit span and several measures of spoken language including word recognition, speech intelligibility, and auditory comprehension in children with CIs. This implies that there are strong relationships between spoken language and working memory. However, when Pisoni and Cleary (2003) examined the correlation of working memory with demographic factors (e.g. age at onset of deafness, duration of deafness, age at implantation, duration of implant use, age, gender, and number of active electrodes), the results were found to be insignificant.

When compared to NH, children with CIs have been found to score lower in verbal short term memory and verbal working memory capacity, both of which have been found to predict later speech and language outcomes (Harris et al., 2013; Kronenberger et al., 2013; Pisoni et al., 2011)

Auditory memory was associated with phonological awareness, receptive and expressive vocabulary knowledge, reading accuracy and comprehension, along with speech intelligibility. In a longitudinal analysis with a large sample of CI users, Pisoni et al. (2011) examined the predictive relationships between auditory memory capacity (digit span) at age 8 to 9 years, and speech intelligibility, vocabulary knowledge and language ability, at approximately 16 years of age. Positive correlations were found between digit span at 8 to 9 years of age and all the speech and language outcome measures in adolescence.

Given all the challenges that deaf children face after cochlear implantation in order to develop speech and language skills, the question arises as to whether these children follow the same path as children with NH regarding lexical acquisition and lexical access in order to communicate with those around them.

4.3 The Mental Lexicon

An area that requires attention in the language development of children with CIs is lexical representation and the processing of underlying word production and comprehension (i.e. spoken word recognition). Although there is evidence that spoken language skills of some CI children are in line with their hearing age peers (Nicholas & Geers, 2008), spoken word recognition remains a challenge for these children.

Challenges in expressive and receptive language development, speech production, and speech perception are considered closely related in children with CI (Rescorla, 2002; Svirsky et al., 2000). Particularly, phonological encoding and storage as well as retrieval of spoken words may be restricted in these children (Schwartz, Steinman, Ying, Mystal, & Houston, 2013).

Following cochlear implantation, the most important elements of language development are lexical acquisition and phonological production and perception. The development of the lexicon and phonology depend on attention to the relevant acoustic-phonetic features, establishment of phonological representations and speech perception (Schwartz et al., 2013). The formation of an initial phonology and lexicon are dependent on early speech perception, selective attention to language-specific acoustic cues, and also to short and long-term memory for those cues (Jusczyk & Hohne, 1997; Nittrouer & Burton, 2005; Werker &

Curtin, 2005). Strong lexical representations involving both phonetic and phonological information are essential for fast and efficient segmentation of the speech signal, word recognition, and novel word learning (Schwartz et al., 2013). Many studies have provided evidence that early speech perception and language abilities are related to later language development (Marchman & Fernald, 2008; Rescorla, 2002, 2005; Trehub & Henderson, 1996; Tsao, Liu, & Kuhl, 2004).

4.4 Factors in lexical access

There are many factors that may affect lexical access. One is neighbourhood density, which will be the focus of the present thesis. As previously stated, lexical neighbours are commonly defined as words that differ by a single sound (Vitevitch, Luce, Pisoni, & Auer, 1999).

Dense neighbourhoods contain many neighbours while sparse neighbourhoods contain few neighbours. Word recognition is negatively affected by high neighbourhood density in adults and children because of greater competition between words (Garlock, Walley, & Metsala, 2001; Vitevitch et al., 1999). Phonotactic probability and neighbourhood density are also correlated in that words from dense neighbourhoods tend to have highly probable phonotactic structure. This has been shown in studies in which phonotactic probability was controlled (Vitevitch & Luce, 2004). These same competitive inhibition effects of denser neighbourhood membership were also found in speech production. For example, both typically developing children and children with word-finding difficulties produce words with few phonological neighbours more accurately (German & Newman, 2004; Newman & German, 2002).

The Lexical Neighbourhood Test (LNT) (Kirk, 1995) as mentioned earlier in chapter 2, is a speech perception test that attempts to gain information about the storage and retrieval of words from the lexicon of children with CIs. The test includes 100 words, half of which are easy while the remaining half are hard. The easy words have low neighbourhood density and high word frequency while the hard words have the opposite properties. Kirk and colleagues used this test with 19 CI children in quiet via live voice with a presentation level of approximately 70-75 dBA. Children were asked to repeat the heard words and in cases where this was not possible, the child was asked to either sign or write the word. Responses were scored as the number of words and phonemes correctly identified. Results revealed that the percentage of words correctly identified from the easy list ranged from 12% to 72% while the words identified correctly from the hard list ranged from 4% to 54%. Also, the scores for the easy words were significantly higher than scores on the hard words. Accordingly, the authors stated that children with CIs use their lexical knowledge to recognize words and that their findings were consistent with the view that the lexicon is organized according to similarity neighbourhoods. They also reported that children with CIs seem to access their lexicon similarly to NH children.

Similar findings were found in children with CIs in other languages using versions of the LNT that were developed according to the same principles as the English LNT. The Cantonese LNT and the Multisyllabic Lexical neighbourhood Test (MLNT) were developed by Yuen et al. (2008) and were applied on 14 children aged 10 and below. Ten of these children used hearing aids while four used cochlear implants. Easy word scores were significantly higher than hard word scores only for the disyllables but not for monosyllables. Another three LNT test versions were developed recently in Mandarin (Liu et al., 2011; Wang et al., 2010; Yang, Wu, Lin, & Sher, 2004; Yuen et al., 2008). However, only the first two tests were verified with children using CIs and results from these tests were mixed. Yang, Wu, Lin, and Lin (2004), for example, developed a monosyllabic Mandarin LNT and applied it on 28 children with CIs. Their results demonstrated that children with CIs scored significantly higher on easy than on hard words. On the other hand, Wang et al. (2010)

applied their Mandarin test on thirty six children using CIs. As opposed to the test developed by Yang, Wu, Lin, and Lin (2004), this test included disyllables as well as monosyllables. Results indicated that easy words had significantly higher scores than hard words for disyllables but not monosyllables. The authors attributed this difference to the increased number of homophones for monosyllables that may have affected lexical access. For further discussion refer to page 67.

From this review, it is clear that speech perception is related to most communicative outcomes that are measured in children with CIs. Therefore, the newly development ALNT seems essential for the clinical assessment of Saudi children using CIs and for comparison with other assessments related to speech and language skills. The development of the ALNT was described in the previous chapter along with results indicating that the test can be used with NH children aged 5 years. In this chapter however, the efficacy of the ALNT is examined for measuring word recognition performance in children with CIs to answer the following questions:

1- Is the ALNT sensitive to expected effects of age at implantation?

To answer this question, children will be grouped based on age at implantation (continuous variable). Their scores on the ALNT will then be compared. Based on previous research, it is hypothesized that the children implanted earlier will perform better. If this is the case here, then it will also assist in assessing the sensitivity of the ALNT.

2- Is the ALNT sensitive to effects of duration of CI use?

For this question, duration of implant use was calculated for each child in years and months. Their scores were then compared based on duration. Much of the research in this area states that increased experience with a CI leads to better outcomes Therefore, it is hypothesized that children with longer experience with their CIs will achieve higher scores.

3- Are lexical effects evident in children using CIs?

As mentioned previously, the ALNT was based on the principles of the Neighbourhood Activation Model (NAM) which assumes that words are organized in the mental lexicon based on “similarity neighbourhoods” and that word recognition is affected by neighbourhood density and word frequency. Owing to this concept, the easy words in the ALNT have high word frequency and low neighbourhood density and the hard words have the opposite characteristics. In the current experiment, lexical effects on speech perception will be apparent in children using CIs if they perform better on the easy than the hard words. Additionally, lexical effects will be explored at group and individual levels.

Because neighbourhood density is higher for the hard words than for the easy words, it is assumed that the errors on hard words will generate more words that are neighbours for the target word than those that are non-neighbours. This assumption will be explored by analysing the errors made by the CI children on the ALNT.

4- How do CI children compare to their NH peers on the ALNT?

This will be investigated by comparing performance of 5 year old NH children in vocoded speech simulating CIs with that of the sample of children with CIs.

Research studies usually compare performance of CI children against NH children tested in similar listening conditions in order to establish baselines for performance. However, with the speech in quiet as presented to children with CIs in this study, NH children would be expected to perform near perfectly, and thus NH children were tested both with speech in noise and with vocoded speech simulating a CI. Vocoder simulations are widely used in studies concerning CIs as they can capture some of the major limitations of listening through a CI, particularly the loss of spectral detail, while the use of NH listeners can eliminate much of the individual variability found in CI subjects (Newman & Chatterjee, 2013). Even though noise vocoded speech may not be entirely comparable to speech heard through a cochlear implant (See page 65 for further discussion), comparing results from these two conditions would at least indicate whether performance is similar between NH children and children with CIs with broadly equivalent degrees of loss of spectral detail.

5- Does repeated administration of the test lists lead to learning effects?

The fact that children need to be assessed continuously at least annually if not every six months in order to measure progress over time denotes that the test lists will be used repeatedly and this may result in children memorizing test items. If so, test results will be biased. In the present study the ALNT word lists were divided in a way that allows the examination of such learning effects by presenting each child with a certain number of words that are repeated across all sessions along with other unrepeated words.

6- How does the sensitivity of the ALNT compare to other speech perception measures?

Because of the lack of availability of other speech perception measures to which the newly developed ALNT can be compared against, we developed a nonsense syllable test to use as a reference for performance on the ALNT. The nonsense syllable test was in the form of consonant-vowels (CV) and included 16 consonants produced in the context of the /a/ and /i/ vowels. Such a test has the advantage of being independent of vocabulary and language levels as well as lexical knowledge (Tye-Murray, 2014). Moreover, since it can be constructed to use sounds from the language of interest and familiar to children, it could be considered as an alternative method for selecting language-appropriate test materials.

7- Can the ALNT measure progress over time?

To achieve this, the test will be applied 3 times with a 6-9 month interval between each testing occasion and the next and the scores from each session will be used to explore the test's sensitivity to detect change in performance over time.

8- Is the ALNT appropriate for use as a clinical assessment tool?

Speech perception tests help not only with measuring outcomes but also in guiding training and rehabilitation to gain maximum benefit from the cochlear implant system (Boothroyd, 1991). In order to fulfil these purposes, the utilized tests should be appropriate for the population that they are intended to be applied in (in this case; Saudi children). Therefore, it was essential that the constructed test contain suitable vocabulary that would be familiar to these children (Kirk, 1997) and that is had good test-retest reliability in measuring outcome. With this in mind, the ALNT test words were drawn from the vocabulary of preschool children aged between 3 and 5 years. The test-retest reliability was established in the previous study with NH children (See Chapter 3 for more details). The findings revealed that the test was reliable for both easy and hard words with the easy words having higher reliability than the hard words. Other factors that make this test clinically useful include ease of administration and ensuring that the children are not fatigued from the test. Combined together, these factors will be evaluated to assess the appropriateness of the ALNT to be used as a clinical assessment tool.

4.5 Method

The experiment involved three assessments with a time interval of 6-9 months between each. This was to assess progress over time as well the effect of repeating test items.

4.5.1 Participants

A sample of 59 children (30 males, 29 females) was recruited from King Abdulaziz University Hospital in Riyadh, Saudi Arabia. Of the 59, 44 children (24 males, 20 females) were included in this study. The remaining children were excluded as they failed to complete the test protocol. Some children dropped out after the first session; at session 2, 36 children completed the test procedure, while at session 3, 26 children completed the test protocol.

The children who participated were aged between 5 and 13.5 years with an average of 8.5 years. Their age at implantation ranged from 1.7 to 11 years with a mean of 4.33 years. The duration of cochlear implant use ranged from 6 months to 9.5 years with an average of 4.3 years. Forty-one of the children were using a Nucleus multichannel cochlear implant whereas 3 were using the MED-EL cochlear implant. Appendix 7.9 displays the form used for collecting patient information.

Selection criteria included: native speaker of Arabic; bilateral profound sensorineural hearing loss; duration of cochlear implant use of at least 6 months, and language level at least equivalent to a typically-developing child of 4 years (i.e. producing and comprehending at least three or four word sentences). Because there are no available standardized language tests in Saudi Arabic, the child's SLT's opinion was used to determine the language level of the child. The procedure used by SLTs for determining language level of CI children is comparing the performance of these children with milestones of normal language development. Based on this, only the children who fulfilled these criteria were tested.

4.5.2 Stimuli

4.5.2.1 Arabic Lexical neighbourhood Test (ALNT)

The ALNT as described in Chapter 3 was used with CI children. It comprised 100 words, 50 of which were easy and 50 were hard. To assess the effect of repetition, twelve of the 50 easy words and 12 of the 50 hard words were presented in all of the three test sessions, while the remaining 38 words from the easy and hard sets were presented only once, in either the first, second, or third session. To accomplish this, the same procedure used in Chapter 3 for assessing test re-test reliability was used except that instead of splitting the words into 3 sub-lists, each set of 50 words was split into 4 sub-lists of 12 (i, j, k, and l) based on the correct scores for each word in Study 1. Sub-list i was repeated in all three sessions whereas sub-lists j, k, and l were presented only once. Eight counterbalanced presentation orders for individual subjects were prepared which also varied the sub-list that was repeated. These orders were then repeated as needed across participant group. The two words that remained after the formation of 4 sub-lists of 12 words were presented in all sessions so that all 50 words were included. Appendix 7.7 shows the design for test presentation.

4.5.2.2 Nonsense CV Test

A nonsense syllable test consisting of 64 consonant-vowel nonsense syllables (CVs) was recorded by two different Saudi female speakers both of whom were used in the test presentation. These speakers were different from the speaker who recorded the ALNT test. The test items consisted of 16 consonants /b, d, ɡ, ħ, j, k, m, r, s, ʃ, t, w, χ, z, ʕ, ɣ / in both /a/ and /i/ contexts. These CV sequences or segments were taken from words in the language samples so that they will be common for the children. Appendix 7.8 shows the CVs that were presented to the children.

4.5.3 Procedure

Children were tested in a sound treated room. For the ALNT, each child was presented with a total of 26 easy words and 26 hard words in the quiet. Words were presented in a random order. The CV test however, was administered in a background of noise to avoid ceiling effects. The noise consisted of speech-spectrum shaped noise matching CCITT recommendation G227. A randomly chosen segment of noise from a 6s long sample was selected on each trial. At playback, the noise commenced 300 ms prior to the presentation of the target speech and both speech and noise co-terminated. A fixed signal-to-noise ratio (SNR) was set individually for each child in the first test session. This was based on the result of a preliminary adaptive test in which the same CV test was used. To find this individualised SNR a 1-up 1-down staircase method was used which converged on the SNR at which performance was 50% correct (Levitt, 1971). The adaptive test continued to run until 12 reversals were recorded. The SNR values ranged from 2.7 to 39.7 with an average of 12.87. The order in which the tests were presented was ALNT first and then the CV test for all children.

Stimulus presentation and response collection were all performed using a script for MATLAB (Mathworks, Natick MA) that ran on a portable PC. Stimuli were presented in the auditory-only modality at 65 dBA via a Fostex 6301B loudspeaker, which was positioned approximately 1 metre away from the child.

For both the ALNT and CV test, the children were asked to verbally repeat the words and syllables they heard and their responses were audio recorded with a Roland R09-HR digital recorder. If the child was unable to produce the word or syllable correctly due to misarticulations, s/he was asked to sign, write or explain the items they heard. All responses were transcribed phonetically. For the spoken responses, if a word was repeated correctly but had misarticulations then it was transcribed twice: once with the misarticulated sounds and another with the corrected sounds, i.e. using the original transcription of the test word. Scoring was based on the transcriptions of the corrected sounds by giving 1 for a correct response and a 0 for an incorrect response. For the signed, written or explained responses, the correct responses were transcribed using the original transcription of the target word. Scoring was the same as that for spoken responses.

4.6 Data Analysis

To investigate the effects of lexical properties (word frequency and neighbourhood density) on speech perception and the capability of the ALNT to measure change in performance over time, a series of Linear Mixed Model (LMM) Analyses were performed on children's ALNT scores for the easy and hard words and the CV scores in each session.

To explore the effects of repetition of ALNT words on performance, a 2 way repeated measures ANOVA was performed on the data.

To compare effects of age at implantation, duration of implant use, and chronological age on performance on both the ALNT and the CV scores, an LMM was performed. The LMM accounted for the correlation between scores collected over the three sessions including a random intercept which represented the individual influence of each child on repeated observations. This type of analysis was used both because it allows a conjoint test of the continuous factor of age with other categorical factors, and because of its robustness with the unbalanced design that resulted from some missing data points at different test intervals. For example, out of the total 44 children who were tested, eight children were only tested once, 10 children had completed two testing sessions, and 26 children completed all three test sessions. The LMM was performed in SPSS. The dependent variable was test score while the independent variables were age at implantation and duration of device use, both which were modelled as continuous variables. The fixed factors were implantation age, duration of device use and session (3 levels). An additional fixed factor was included for the ALNT only which was word difficulty (easy and hard). For the ALNT, all interaction terms were initially included in the model and non-significant interactions were then removed when this led to a decrease of the Akaike information criterion (AIC) and hence a better fit. In both the ALNT and the CV models, subject was included as a random effect including the intercept for subjects. Age at implantation and duration of CI use were considered as covariates. For both models, an unstructured covariance type was used for the repeated measures and a variance component was used for the random factor. The effect of chronological age was investigated using LMMs however it was included alone in a separate model to make the analysis more feasible. The fixed factors for this model were session and difficulty in addition to chronological age for the ALNT whereas for the CV test the fixed factors were session and chronological age. In both models, score was the dependent variable. The LMMs were performed twice for each of the ALNT and the CV scores. The first time it included all 44 children and the second time it included only the 26 children who completed all sessions.

4.7 Results

4.7.1 Effect of implantation age

The age at cochlear implantation for the children who were included in the analysis ranged from 1.7 to 11 years with a mean of 4.33 years. And given that it is well documented that earlier implantation leads to better speech perception performance, the current study investigated whether this effect would be apparent in performance on the ALNT.

Results of the first LMM analysis revealed that for the 44 children, the effect of age at implantation on performance on the ALNT was insignificant [$F(1,46.08) = 2.08$, p=0.155]. However, when only the 26 children who completed all three sessions were included in the second LMM model, the effect of age at implantation was found to be significant [$F(1,23) = 4.50$, p=0.04]. The difference between these two outcomes may have been a result of the weakened power of the test with the need to adjust for missing data. The sample of 44 children included children who only completed one third of the test and others who completed only two thirds and this may have caused the statistically insignificant effect of age at implantation.

Regarding the rest of the factors included in the analysis, the effect of word difficulty as expected and similar to was what was found in Chapter 3 with NH children, the effect of word difficulty was significant for the sample of 44 children [$F(1,40.16) = 219.15$, $p<0.001$] and 26 children [$F(1,25) = 156.70$, $p<0.001$]. Also as expected and seen previously in Chapter 3, the effect of session was significant for the sample of 44 children [$F(2,33.58)= 11.91$, p=0.001] and 26 children [$F(2,25)= 11.77$, p=0.001]. This indicates that easy words were indeed different from easy words and that the performance of children did differ from one session to the next. Also, there was no interaction between word difficulty and session for the sample of 44 children [$F(2,32.78)= 1.36$, p=0.027] nor the sample of 26 children [$F(2,25)= 1.95$, p=0.16] which demonstrates that the effects of these two factors were independent of each other.

Table 4.1 and Table 4.2 below show the fixed factors that were included in the final models and their significance after application of the AIC.

Table 4.1: Fixed effects included in the final model of 44 children for the effect of age at implantation and duration.

Fixed effects	F	Significance
Word difficulty	*F(*1,40.16)= 219.15	*p*<.001
Session	*F(*2,33.58)= 11.91	*p*<.001
Implantation age	*F(*1,46.08)= 2.08	*p*=0.15
Duration	*F(*1,37.05)= 0.119	*p*=0.73
Word difficulty*Session	*F(*2,32.78)= 1.36	*p*= 0.27

Table 4.2: Fixed effects included in the final model of 26 children for the effect of age at implantation and duration.

Fixed effects	F	Significance
Word difficulty	*F(*1,25)= 156.70	*p*<.001
Session	*F(*2,25)= 11.77	*p*<.001
Implantation age	*F(*1,23)= 4.50	*p*=0.04
Duration	*F(*1,23)= 0.01	*p*=0.91
Word difficulty*Session	*F(*2,25)= 1.95	*p*= 0.16

The spread of scores for the 44 CI children based on age of implantation in Figure 4.21 shows that scores tend to increase with a decrease in age at implantation even though there was no statistically significant effect of implantation age. In Figure 4.2, although there is a lot of individual variability, the effect of age at implantation is more prominent and children who are implanted earlier are doing much better than children who were implanted at a later age which is consistent with the statistically significant effect.

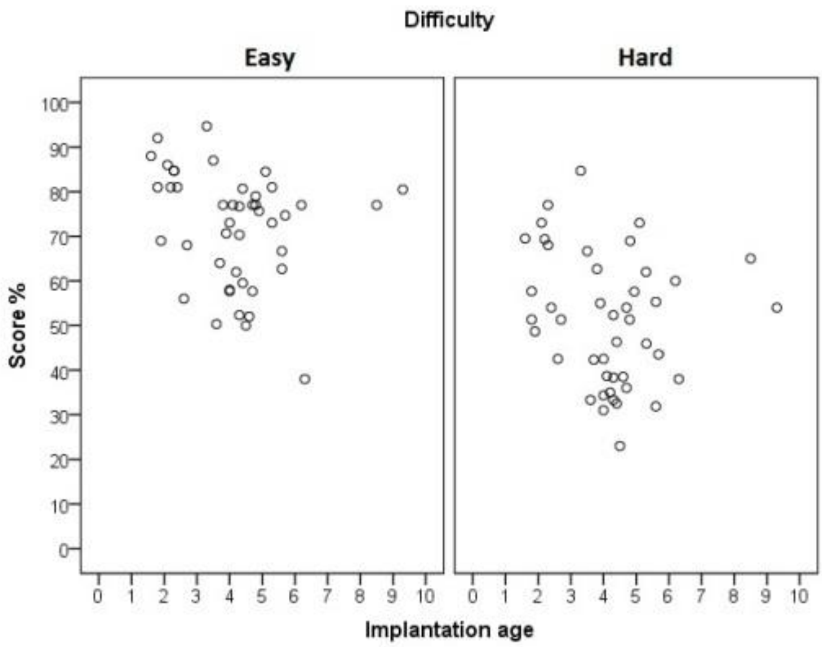


Figure 4.1: Distribution of easy and hard word scores for the 44 CI children over age of implantation.

Figure 4.2: Distribution of easy and hard word scores for the 26 CI children over age of implantation.

4.7.2 Effect of duration of device use

Children included in this analysis had a duration of cochlear implant use that ranged from 6 months to 9.5 years with an average of 4.3 years. It was expected that increased experience with a cochlear implant device would lead to better speech perception skills, and so the present study included a test of whether this effect would be evident with the ALNT.

The same LMM Analysis used for age at implantation was also used to investigate the effect of duration of CI use with session in the whole sample (N=44) and in those who completed all three sessions (N=26) (Tables 4.1 and 4.2). Duration of device use was not significant in the group of 44 CI children [$F(1,37.05) = 0.119$, $p=0.732$] nor was it significant in the group of 26 children [$F(1,23)= 0.01$, $p=0.91$] suggesting that an increase in experience with the CI did not lead to higher scores on the ALNT.

When the scores of the CI children were plotted based on length of implant use Figure 4.3 and Figure 4.4), there was a slight tendency for the score to increase with an increase in experience with the implant device, however this was not significant.

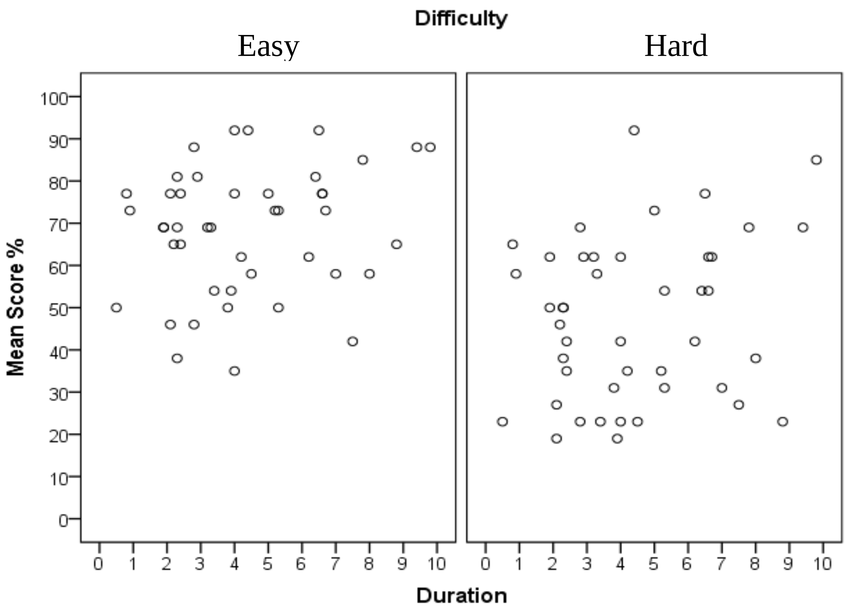


Figure 4.3: Distribution of easy and hard word scores for the 44 CI children over duration (in years) post implantation.

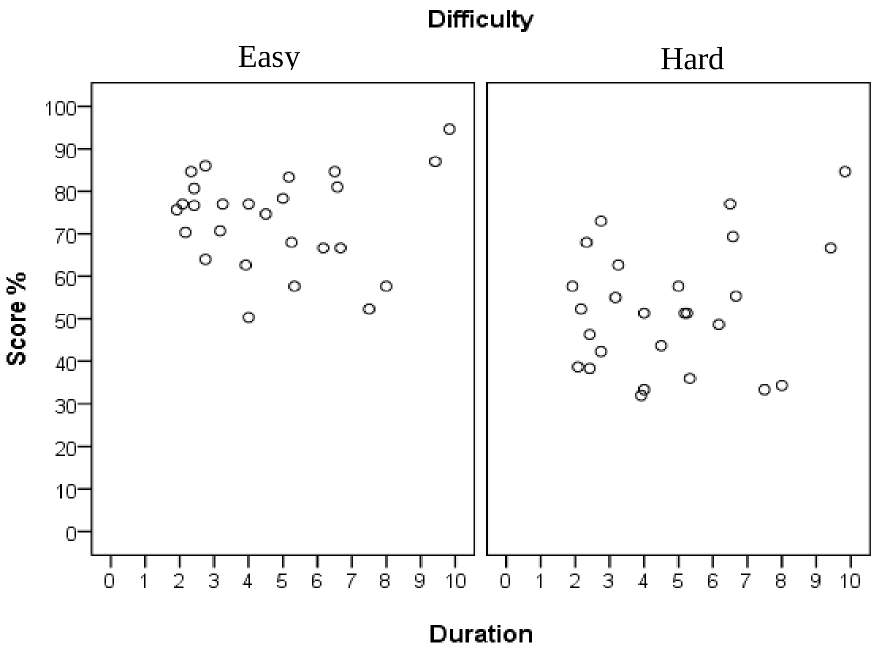


Figure 4.4: Distribution of easy and hard word scores for the 26 CI children over duration (in years) post implantation.

4.7.3 Effect of chronological age

It may well be that development of speech perception improves with age as it is linked with cognitive and other speech and language skills. In order to see whether chronological age had an impact on speech perception performance, children's scores on the ALNT were plotted based on chronological age. Figure 4.5 and Figure 4.6 display this distribution. The spread of scores shows that there is no obvious effect of chronological age and children that are younger are doing as well as children who are older. This effect was further tested by an LMM analysis that included chronological age, session, difficulty, and difficulty*session as fixed factors while subjects was the random factor. Results revealed that the effect of chronological age was not significant for the sample of 44 CI children [$F(1,38.10) = 0.07$, $p=0.78$] nor for the sample of 26 CI children [$F(1,24)= 0.98$, $p=0.33$] . Table 4.3 and Table 4.4 illustrate the factors included in the models and their significance.

As expected, the effect of word difficulty was significant in both the 44 and the 26 sample of children, [$F(1,40.88)= 227.89$, $p<.001$] and [$F(2,32.78)= 1.36$, $p<0.001$] respectively. Similarly, the effect of session was also significant for the sample of 44 and 26 children and was [$F(2,34.25)= 13.55$, $p<.001$] and [$F(2,25)= 11.77$, $p<0.001$] respectively. However, there was no interaction between word difficulty and session in the sample of 44 children [$F(2,32.94)= 1.16$, $p=.32$] nor the sample of 26 children [$F(2,25)= 1.95$, $p=0.16$]. As previously mentioned, this also shows that the effects of word difficulty and session are independent of each other.

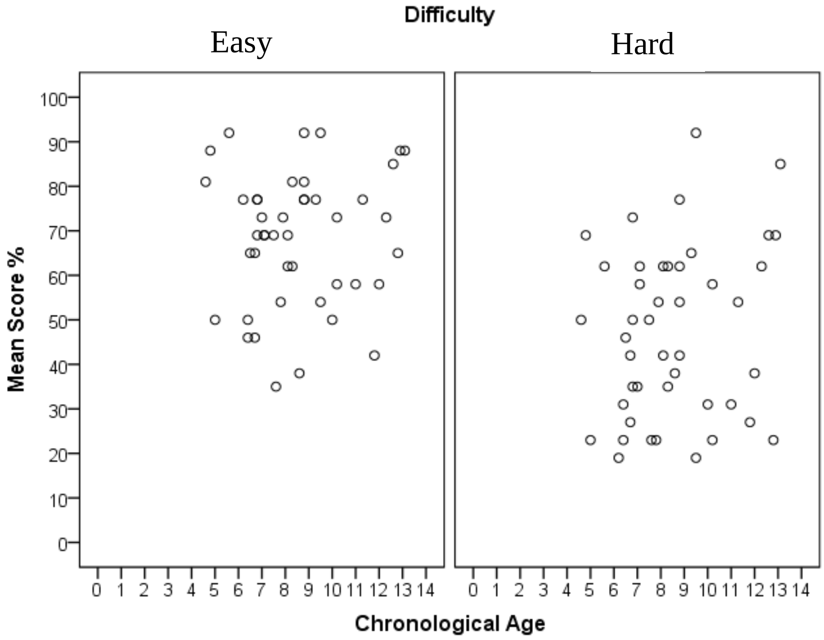
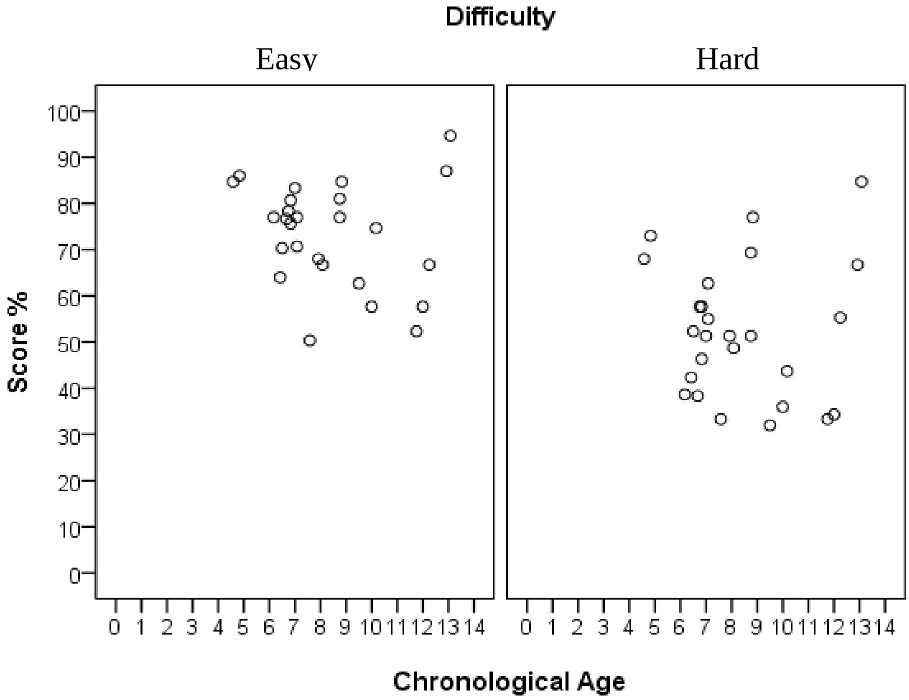


Figure 4.5: Distribution of easy and hard word scores for the 44 CI children over chronological age (in years).

Table 4.3: Fixed effects included in the final model including 44 CI children for the effect of chronological age.

Fixed effects	F	Significance
Word difficulty	$F(1,40.88) = 227.89$	$p < .001$
Session	$F(2,34.25) = 13.55$	$p < .001$
Chronological age	$F(1,38.10) = 0.07$	$p = 0.78$
Word difficulty*Session	$F(2,32.94) = 1.16$	$p = 0.32$



lren over

chronological age (in years).

Table 4.4: : Fixed effects included in the final model including 26 CI children for the effect of chronological age

Fixed effects	F	Significance
Word difficulty	*F*(1,25)= 156.70	*p*<.001
Session	*F*(2,25)= 11.77	*p*<.001
Chronological age	*F*(1,24)= 0.98	*p*=0.33
Word difficulty*Session	*F*(2,25)= 1.95	*p*= 0.16

4.7.4 ALNT over sessions

4.7.4.1 Group analysis

The performance of children on easy and hard words in all three sessions is shown below in Figure 4.7. In this figure, the children are grouped based on the number of sessions they completed. The white box represents the children who completed the first session only; the dotted boxes represent the children who completed both the first and second session, while the striped boxes represent the children who completed all three sessions. It can be seen from Figure 4.7 that the range of scores is fairly similar between the children who completed 1, 2, and 3 sessions. Thus, children who dropped out in the second and third session did not affect performance on a group level.

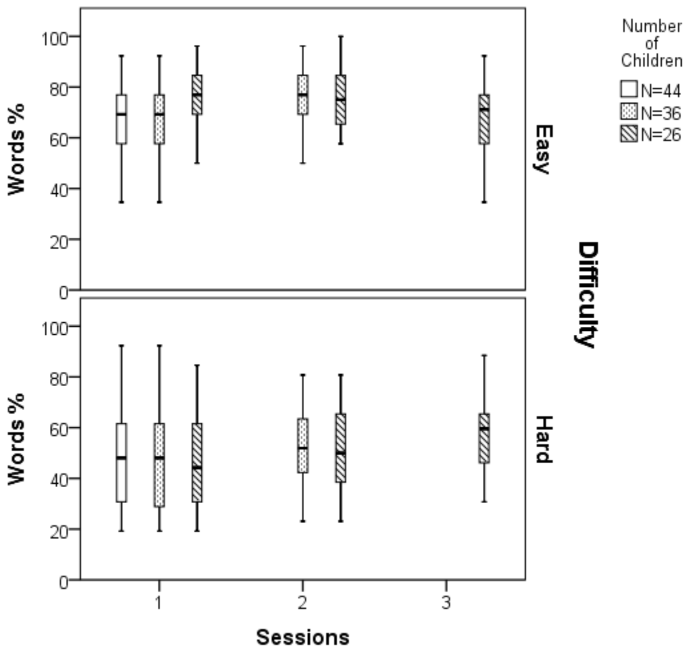


Figure 4.7: Percent words correct scores for easy and hard words in the first, second, and third session based on number of words correct out of 26.

The white box shows the group of children who completed session 1, the dotted boxes show the children who completed sessions 1 and 2, and the striped boxes show the children completing all 3 sessions. The box shows the inter-quartile range and the bar represents the median score. Whiskers indicate the range excluding outliers.

The LMM analysis revealed that there was a significant effect for session indicating that children's scores were significantly different from session 1 to session 2 and from session 2 to session 3. Regarding the effect of sessions, for both groups of CI children, the improvement from session 1 to session 2 was 6% for the easy words and 4.6% for the hard words whereas the improvement in performance from session 2 to session 3 was around 1.5% for easy words and 7.5% for hard words. There was no significant interaction between the factors of word difficulty and session (Table 4.1 and Table 4.2).

Tests of within-subject contrasts for the 26 children showed that the difference between scores in session 1 and session 2 was highly significant [$F(1,25) = 6.47$, $p = .18$] as was the difference between sessions 2 and 3 [$F(1,25) = 10.71$, $p = 0.003$] which indicates that there is a positive change in children's performance from one session to the other. The size of the difference between session 1 and 2 and sessions 2 and 3 was 5.4% and 4.5% respectively.

The LMM analysis also revealed that there was also a significant effect of word difficulty which demonstrates that the easy words received significantly higher scores than the hard words (Table 4.1and Table 4.2). This can also be observed when looking at mean scores of the whole sample for easy words for sessions 1 (N=44), 2 (N=36), and 3 (N=26) which were 68.63%, 74.85%, and 76.33% respectively and the mean scores for the hard words across sessions 1, 2, and 3 which were 46.73%, 51.33%, and 58.87% respectively. A similar pattern is also observed for the group of 26 children by looking at the means for easy words for sessions 1, 2, and 3 which were 68.57%, 74.88%, and 76.38% respectively and the mean scores for the hard words across sessions 1, 2, and 3 which were 46.76%, 51.34%, and 58.84% respectively.

4.7.4.2. Individual Variability in ALNT Scores

A binomial model incorporating both a subject's speech perception score and the number of test items (25) was used to predict the variability among scores on the ALNT. This allows us to asses individually whether scores change from session to session more than would be expected on the basis of binomial variability. Binomial 95% confidence limits were thus calculated for individual subject's scores on the easy and hard words for each session. Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11, Figure 4.12, and Figure 4.13 show each subject's score for a reference session (1 or 2) with the 95% CI plotted against scores from session 2 and 3. This shows that for the easy words the percentage of children whose changes of score were within the binomial variability range was 89%, 88% and 73% for sessions 1and 2, 2 and 3, and 1and 3 respectively. For the hard words the percentage of children within this range was 69%, 88%, and 65% for sessions 1and 2, 2 and 3, and 1and 3 respectively. It is essential to note that it was very rare for children to score lower than the expected limit from an earlier score, however, a few children scored higher than the expected range from an earlier score and this is consistent with an improvement in performance over time.

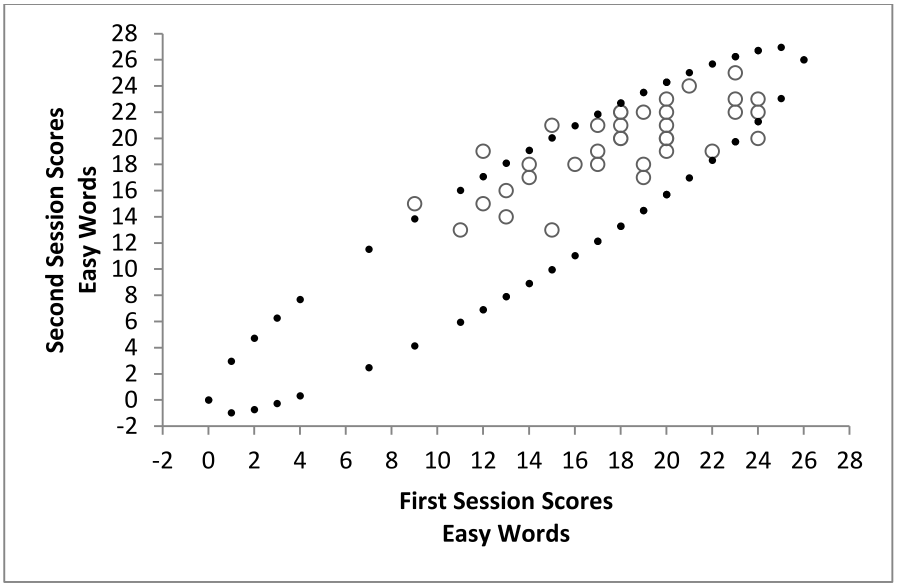


Figure 4.8: Scatter plot showing the change at individual level for CI children's easy word scores from the first to the second session. The dots represent the individual confidence intervals for session 1.

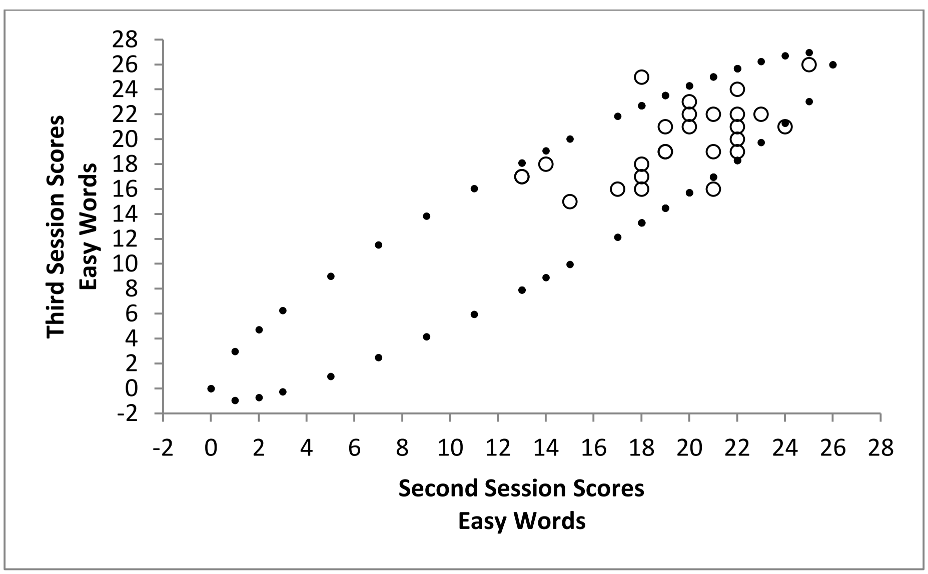


Figure 4.9: Scatter plot showing the change at individual level for CI children's easy word scores from the second to the third session. The dots represent the individual confidence intervals for session 2.

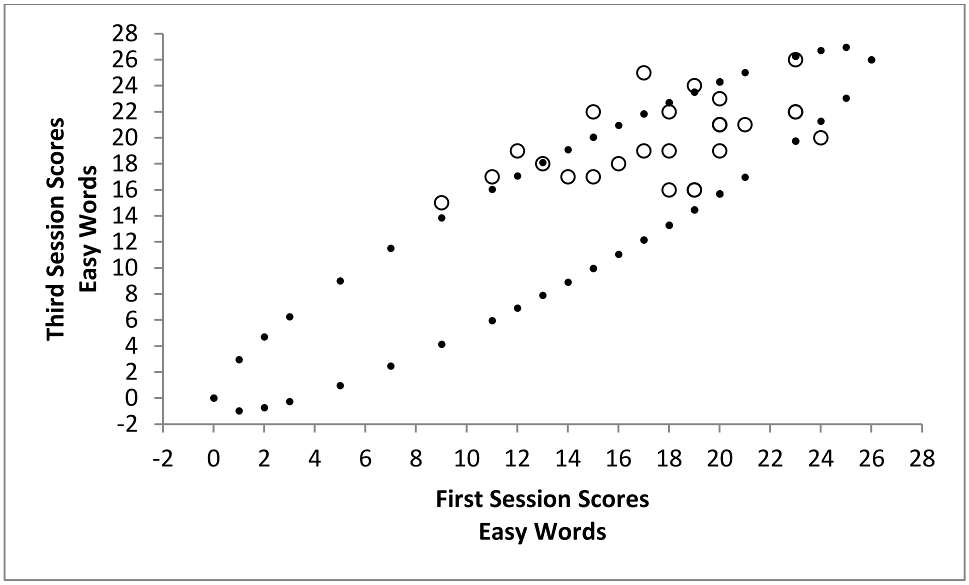


Figure 4.10: Scatter plot showing the change at individual level for CI children's easy word scores from the first to the third session. The dots represent the individual confidence intervals for session 1.

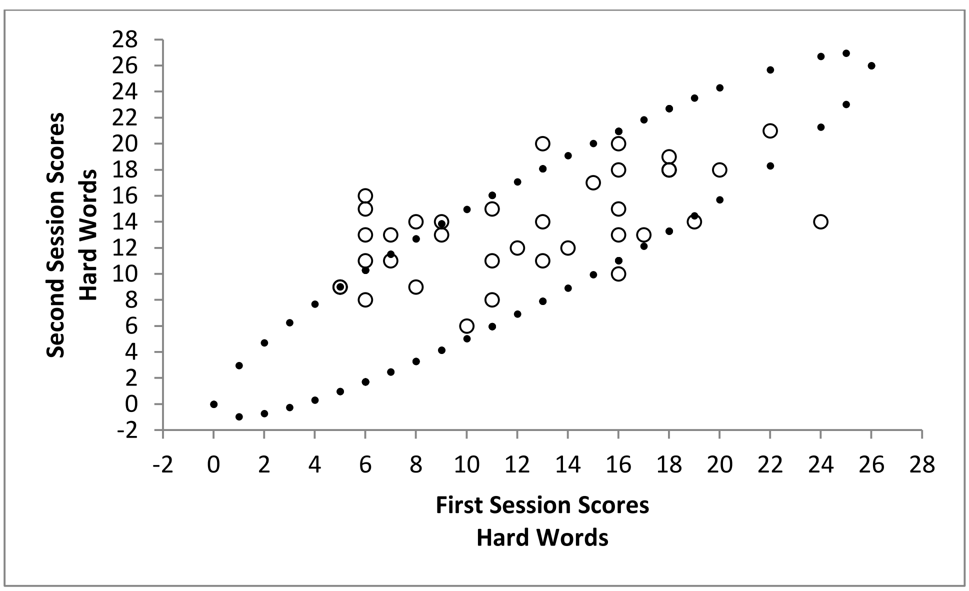


Figure 4.11: Scatter plot showing the change at individual level for CI children's hard word scores from the first to the second session. The dots represent the individual confidence intervals for session 1.

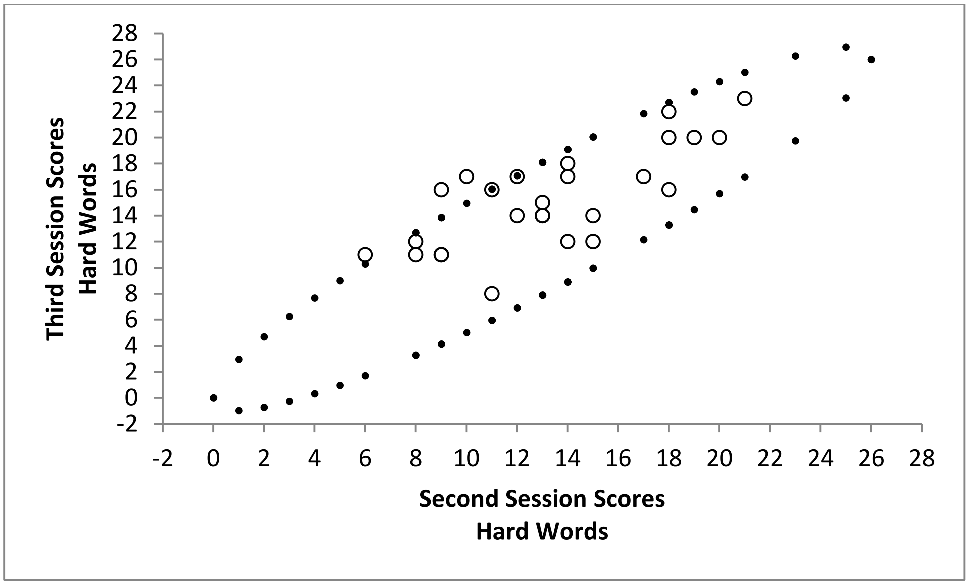


Figure 4.12: Scatter plot showing the change at individual level for CI children's hard word scores from the second to the third session. The dots represent the individual confidence intervals for session 2.

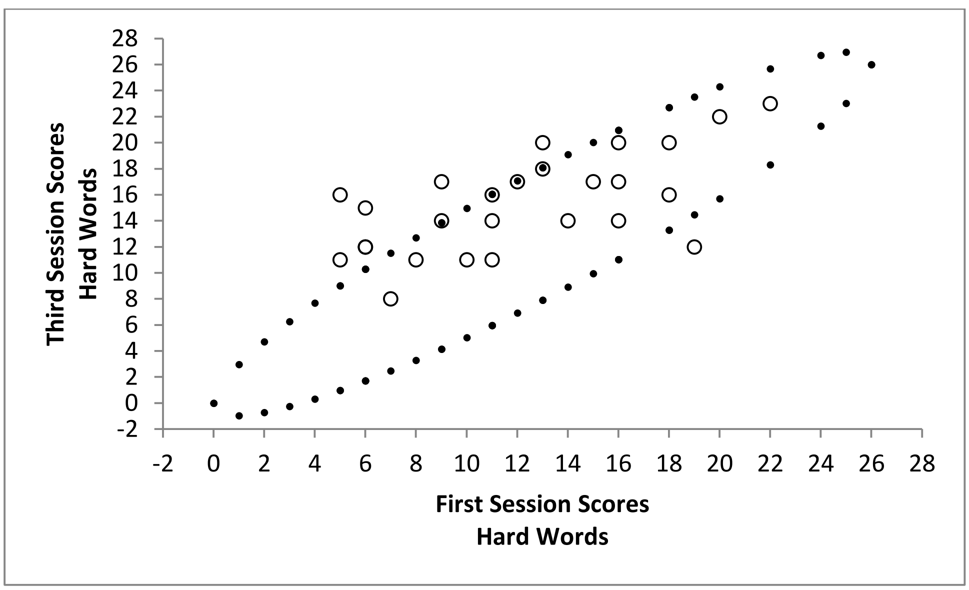


Figure 4.13: Scatter plot showing the change at individual level for CI children's hard word scores from the first to the third session. The dots represent the individual confidence intervals for session 1.

4.7.5 Analysis of neighbour and non-neighbour errors for CI children

According to the NAM theory, if performance on the easy words exceeds performance on the hard words, then this would be consistent with the view that words are stored in the lexicon according to similarity neighbourhoods. Another way of testing this would also be looking at children's errors on the easy and hard words. The errors on the hard words would be expected to include more neighbours than non-neighbours. To investigate this, the type of errors that were produced by the children for each word was analysed using the same procedure as that described in Chapter 3(See page 82 for further details).

A Chi-square analysis revealed a significant difference between the type of errors produced for easy and hard words: ($\chi 2 = 36.27$, df= 1, $p<.01$). For the easy words, inspection of the observed and expected proportions revealed that the neighbour errors were lower than expected while the non-neighbour errors were higher than expected. The opposite pattern was observed in the hard word error scores.

When looking at the word counts for each target word, none of the errors for the easy words had more neighbour than non-neighbour errors. For the hard words however, only 1 out of the 50 words had more neighbour than non-neighbour errors while for the remaining 49 hard words, the number of non-neighbour errors was higher than the neighbour errors. Figure 4.14 displays the percentages of neighbour and non-neighbour errors for both easy and hard words.

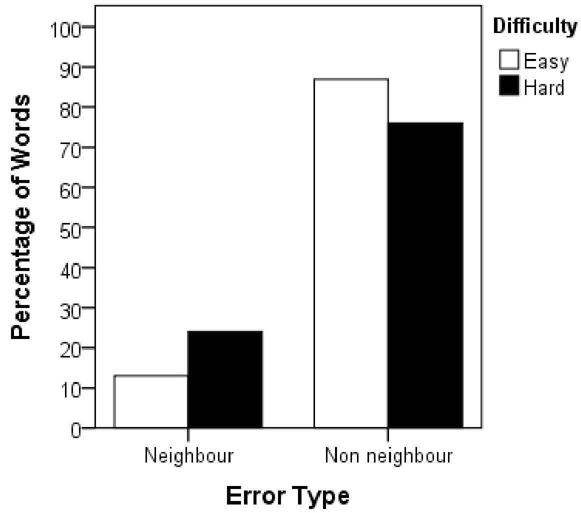


Figure 4.14: Percentage of words that are neighbour errors and words that are non-neighbour errors for both easy and hard words.

4.7.6 Comparison with age-matched normal hearing children

The performance of the 5-7 year old children with CIs against that of the CI simulation results from 5 year old NH children is shown in Figure 4.15. Inspection of the scatter plot reveals that, with 5 exceptions out of 12, the performance of the children with CIs on the easy list exceeded that of NH children listening to a 4 channel vocoder, while performance on the hard list (also with a few exceptions) was broadly comparable with NH peers listening to an 8 channel vocoder.

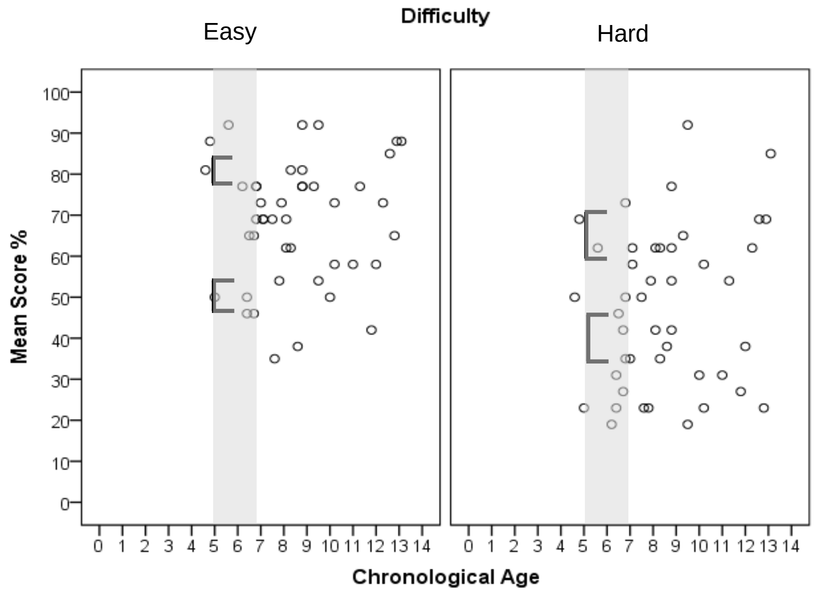


Figure 4.15: Distribution of easy and hard word scores for the CI children based on chronological age in years.

The braces indicate the performance of 5 year old NH children via 4 and 8 spectral channels. The shaded area shows age range of children using CIs who are being compared to NH children.

4.7.7 Repetition effects for ALNT

Differences between sessions in ALNT scores for repeated and non-repeated items are shown in Figure 4.16, Figure 4.17, and Figure 4.18. To determine if there was an effect of repetition for the repeated words between sessions 1 and 2, a repeated 2-way Analysis of Variance (ANOVA) was conducted on the difference between scores in the first and second session for both easy and hard words. This showed no significant effect of repetition [$F(1,22) = .00$, $p = .1$]. Nor was there an interaction between the word difficulty and repetition factors [$F(1,22) = 1.21$, $p = .28$]. A similar ANOVA was administered to check for repetition effects between sessions 2 and 3. Similar to the previous analysis, no main effect of repetition was found [$F(1,22) = 2.00$, $p = .17$] and there was again no interaction between repetition and word difficulty [$F(1,22) = 1.13$, $p = .29$]. The same statistical procedure was repeated for sessions 1 and 3 for both easy and hard word scores. There was no main effect of repetition [$F(1,22) = 3.28$, $p = .08$] and no interaction between repetition and word difficulty [$F(1,22) = .15$, $p = .70$].

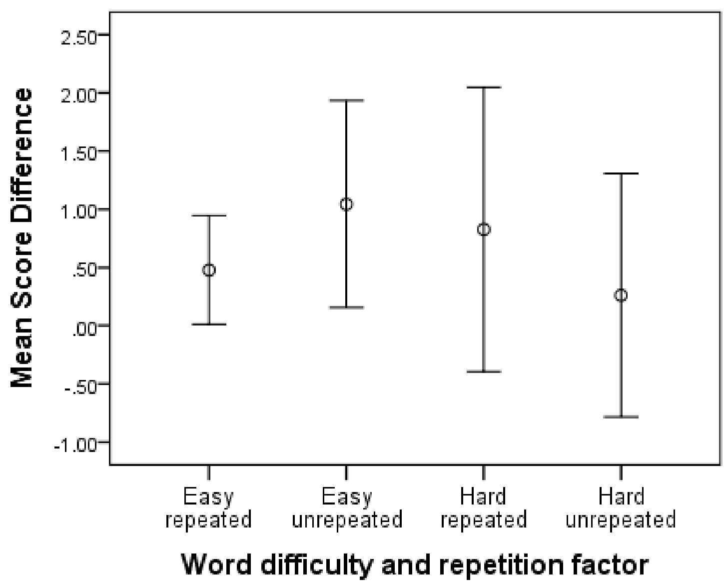


Figure 4.16: Difference score (words) between session 1 and 2 for repeated and unrepeated words for the easy and hard lists.

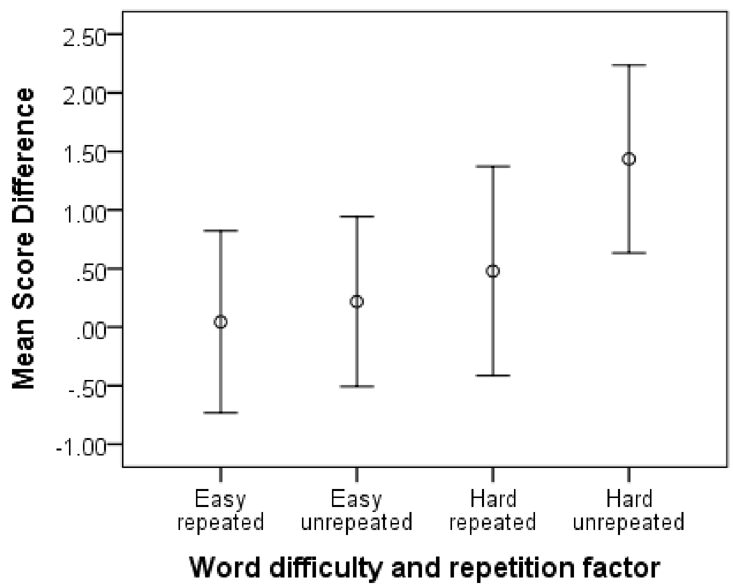


Figure 4.17: Difference score (words) between sessions 2 and 3 for repeated and unrepeated words for the easy and hard lists.

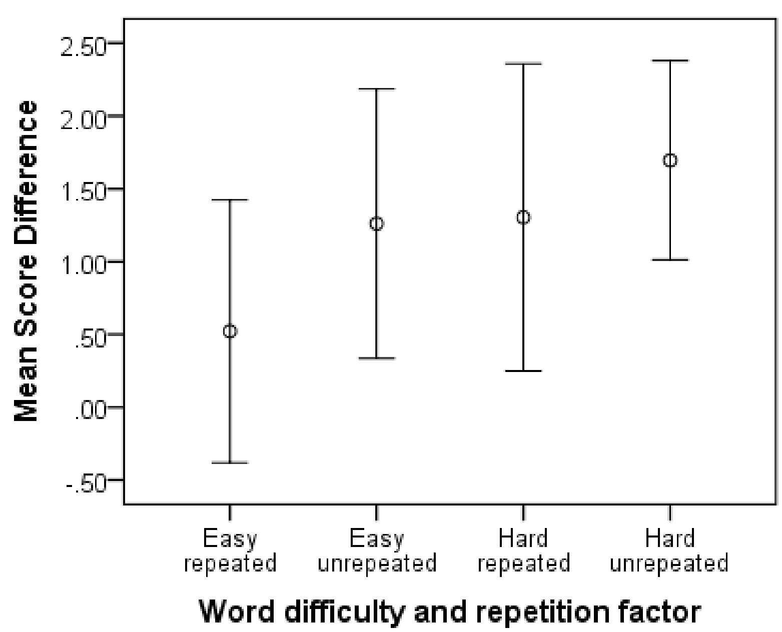


Figure 4.18: Difference score (words) between sessions 1 and 3 for repeated and unrepeated words for the easy and hard lists.

4.7.8 Nonsense CV Syllable Test Scores

4.7.8.1 Effect of implantation age

For the Nonsense CV syllable test, the percentage of correct responses (either repeated verbally or written) was calculated across the 44 children, 36 children, and 26 children, who attended the first, second and third sessions respectively. Mean scores for sessions 1, 2, and 3 were 53.65%, 59.46%, and 65.14%.

Results revealed that the effect of age at implantation on performance on the CV test was insignificant for the group of 44 children [$F(1,50.79) = .026$, $p=0.87$] and the group of 26 children [$F(1,23) = .49$, $p=0.48$]. Conversely however, and as observed in the ALNT analysis, the effect of session was significant for group of 44 children [$F(2,33.55) = 174.42$, $p<0.001$] and the group of 26 children [$F(2,25) = 9.47$, $p<0.001$]. This indicates that the performance of children on the CVs was different from session to the next. Table 4.5 and Table 4.6 below show the fixed factors that were included in the final models and their significance after application of the AIC.

Table 4.5: Fixed effects included in the final model that included 44 children for the effect of age at implantation and duration.

Fixed effects	F	Significance
Session	$F(2,33.55) = 174.42$	$p<.001$
Implantation age	$F(1,50.79) = .026$	$p=0.87$
Duration	$F(1,39.16) = 0.33$	$p=0.56$

Table 4.6: Fixed effects included in the final model that included 26 children for the effect of age at implantation and duration.

Fixed effects	F	Significance
Session	$F(2,25)= 9.47$	$p=0.001$
Implantation age	$F(1,23)= 0.49$	$p=0.48$
Duration	$F(1,23)= 0.06$	$p=0.80$

The spread of scores for the CI children based on age of implantation in

Figure 4.19 and Figure 4.20 shows that scores tend to be even across all ages thereby supporting the statistically insignificant effect of implantation age.

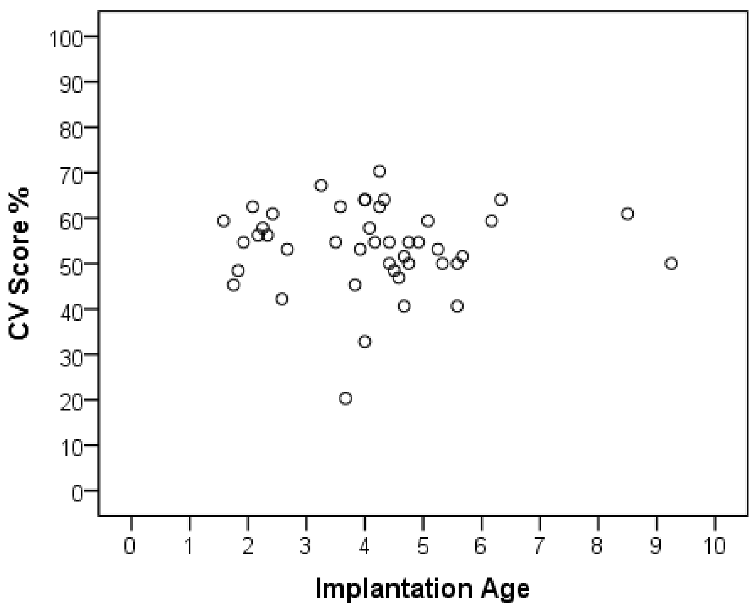


Figure 4.19: Distribution of CV scores for the 44 CI children over age of implantation.

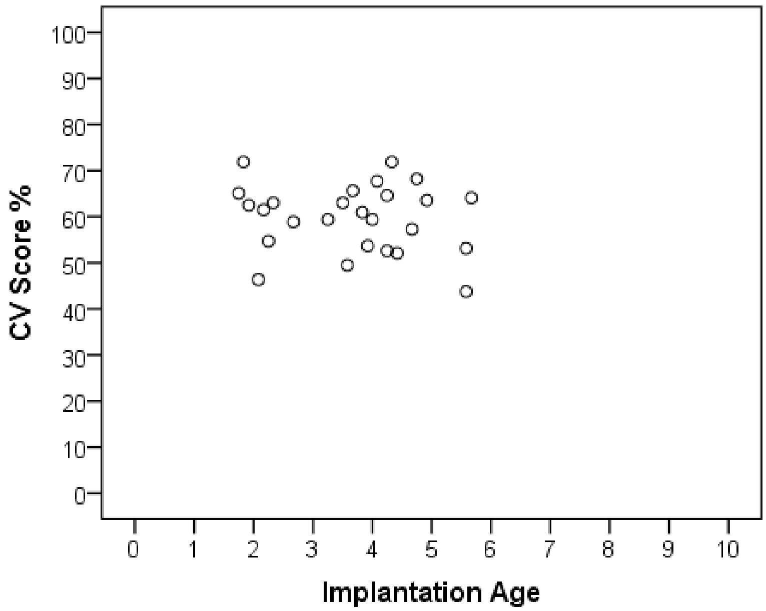


Figure 4.20: Distribution of CV scores for the 26 CI children over age of implantation.

4.7.8.2 Effect of duration of device use

The same LMM analysis used for age at implantation was also used to investigate the effect of duration of CI use with session (Tables 4.5 and 4.6). As with age at implantation, duration of device use was not significant for the group of 44 children [$F(1,39.16)= 0.33$, $p=0.56$] nor the group of 26 children [$F(1,23)= 0.06$, $p=0.80$] suggesting that an increase in experience with the CI did not lead to higher scores on the CV test.

When the scores of the CI children were plotted based on length of implant use (Figure 4.21 and Figure 4.22), there is no tendency for the score to increase with an increase in experience with the implant device which confirms that this effect is not significant.

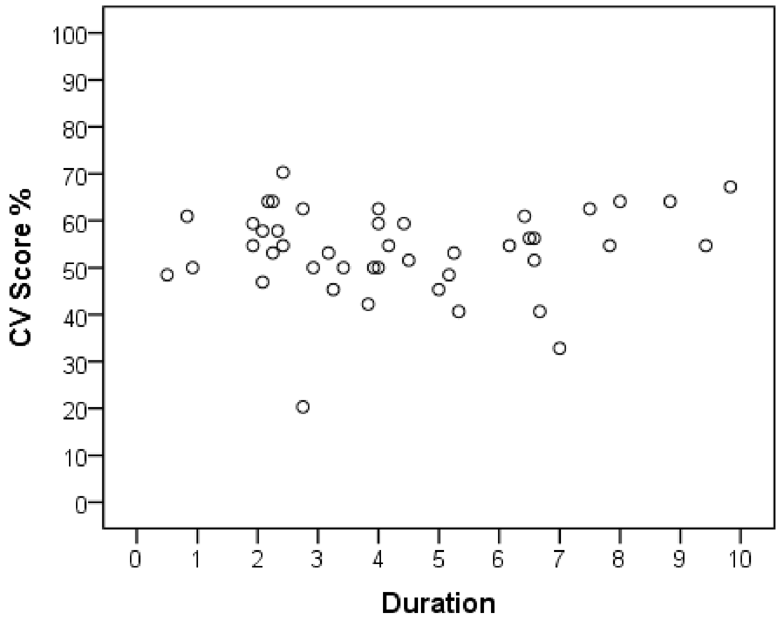


Figure 4.21: Distribution of CV scores for the 44 CI children over duration (in years) post implantation.

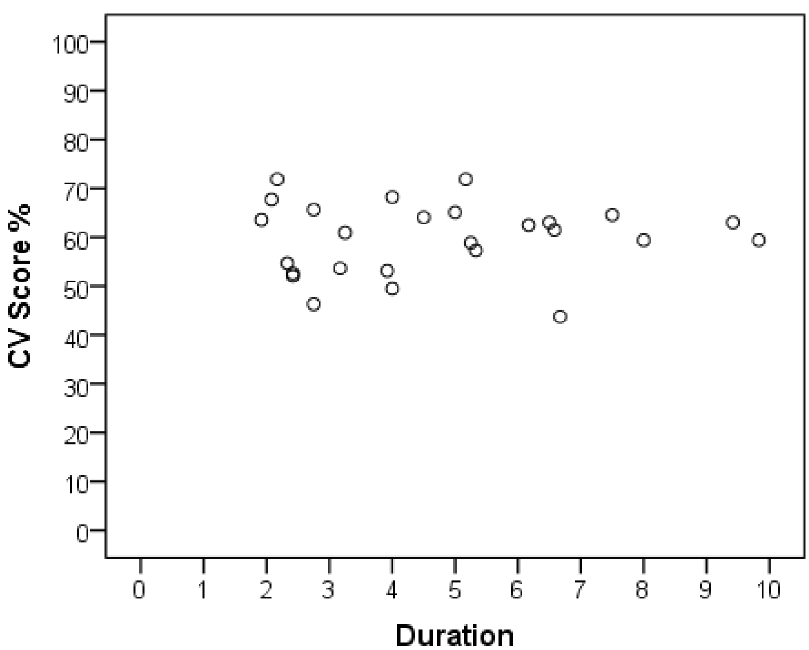


Figure 4.22: Distribution of CV scores for the 26 CI children over duration (in years) post implantation.

4.7.8.3 Effect of chronological age

In order to see whether chronological age had an impact on speech perception performance, children's scores on the CV test were plotted based on chronological age. Figure 4.23 and Figure 4.24 display this distribution. The spread of scores shows that there is no obvious effect of chronological age and children that are younger are doing as well as children who are older. This effect was further tested by an LMM analysis that included chronological age and session as fixed factors while subjects was the random factor. Results revealed that the effect of chronological age was not significant in the group of 44 children [$F(1,39.88)= 0.31$, $p=0.58$] nor the group of 26 children [$F(1,24)= 0.01$, $p=0.94$]. The effect of session however was significant in both groups and was [$F(2,34.03)= 14.57$, $p<0.001$] for the group of 44 children and [$F(2,25)= 9.47$, $p<0.001$] for the group of 26 children, indicating that CV scores differed from one session to the next regardless of chronological age. Table 4.7 and Table 4.8 illustrate the factors included in the model and their significance.

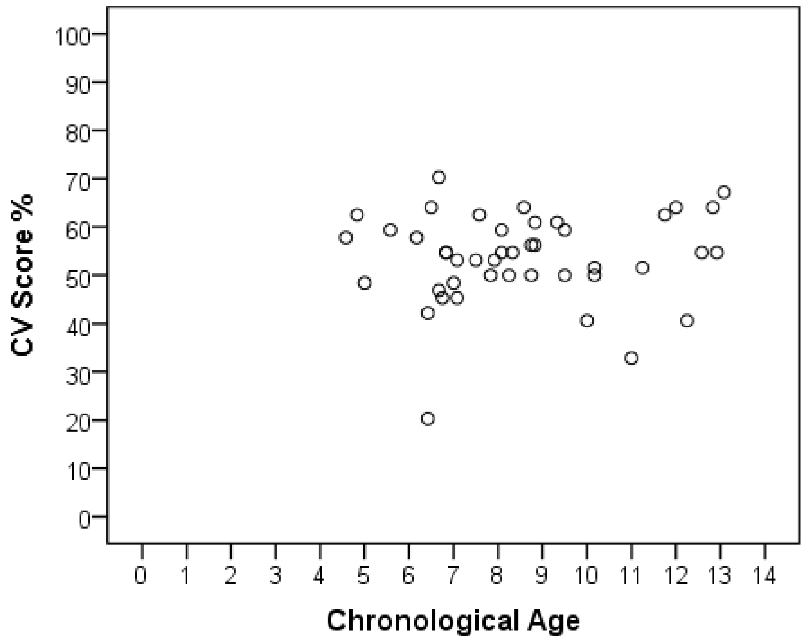


Figure 4.23: Distribution of CV scores for the 44 CI children over chronological age (in years).

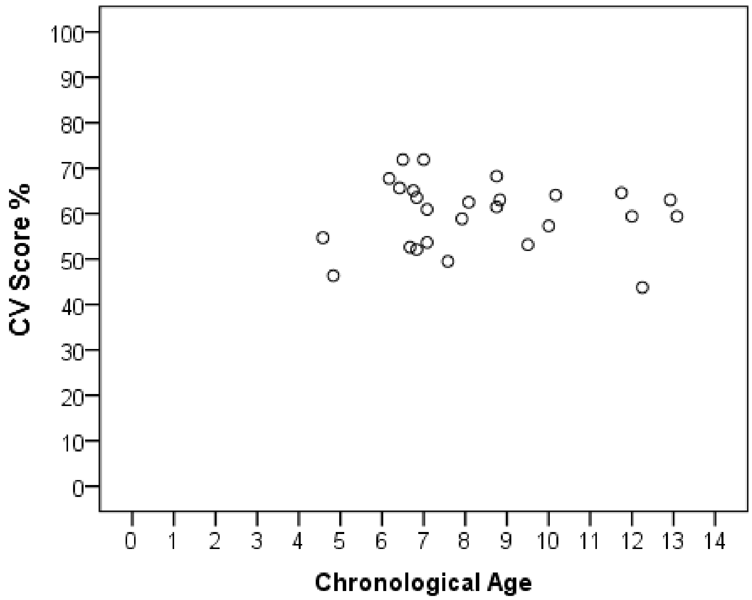


Figure 4.24: Distribution of CV scores for the 26 CI children over chronological age (in years).

Table 4.7: Fixed effects included in the final model including 44 CI children for the effect of chronological age.

Fixed effects	F	Significance
Session	$F(2,34.03) = 14.57$	$p < .001$
Chronological age	$F(1,39.88) = 0.31$	$p = 0.58$

Table 4.8: Fixed effects included in the final model including 26 CI children for the effect of chronological age.

Fixed effects	F	Significance
Session	$F(2,25)= 9.47$	$p=0.001$
Chronological age	$F(1,24)= 0.01$	$p=0.94$

4.7.8.4 CV Test over sessions

4.7.8.4.1 Group Analysis

As with the ALNT, the children in Figure 4.25 are grouped based on the number of sessions they completed. The white box displays the children who completed session 1, the dotted boxes shows those who completed sessions 1 and 2 and the striped boxes shows the children who completed all 3 sessions. The range of scores between the three groups of children is quite similar indicating that the children who dropped out in sessions two and three did not affect performance at a group level.

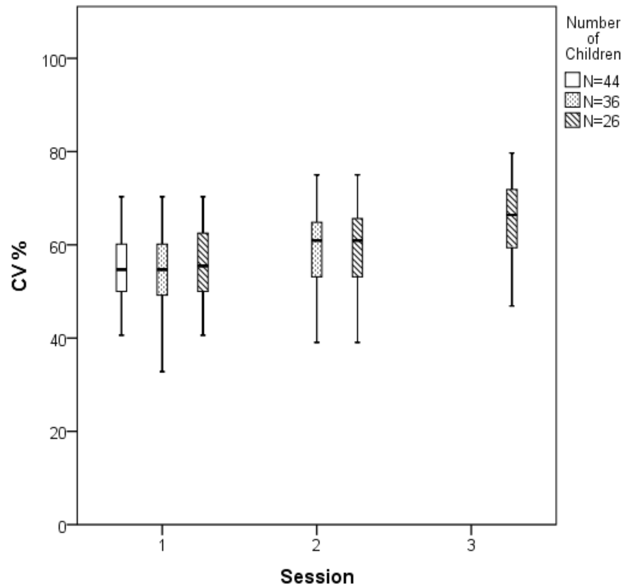


Figure 4.25: Percent scores for the Nonsense syllable test in the first, second, and third session based on number of consonant vowels correct out of 64.

The white box shows the group of children completed session 1 only, the dotted boxes show the children who completed the first and second sessions, and the striped boxes shows the children who completed all three sessions. The box shows the inter-quartile range and the bar represents the median score. Whiskers indicate the range excluding outliers.

To analyse change in children's performance on the Nonsense Syllable Test, a Linear Mixed Model Analysis (LMM) was performed on the CV scores with session, implantation age, and duration as fixed factors and subjects as a random variable. Results revealed that the effect of session was significant for the group of 44 CI children [$F(2,34.03)= 14.57$, $p< 0.001$] and the group of 26 CI children [$F(2,25)= 9.47$, $p=0.001$] indicating that scores differed significantly from one session to the next. Tables 4.7 and 4.8 above show the fixed factors that were included in the models and their significance after application of the AIC.

Tests of within-subject contrasts for the 26 children revealed that this difference was significant both from session 1 to session 2 [$F(1,25) = 6.23$, $p = 0.019$], and from session 2 to session 3 [$F(1,25) = 10.29$, $p < 0.004$] which indicates that there is a positive change in children's performance from one session to the other. The size of the difference between sessions 1 and 2 and sessions 2 and 3 was 5% and 5.5% respectively.

4.7.8.4.2 Individual Variability in CV Scores

Using the same binomial model that was used for predicting scores for the ALNT, individual variability for the CV scores was calculated. The percentage of children scoring on the CVs within the expected binomial range was 78%, 73%, and 54% for sessions 1 and 2, 2 and 3, and 1 and 3 respectively. Figure 4.26, Figure 4.27, and Figure 4.28 show each subject's score for a reference session (1 or 2) with the 95% CI plotted against scores from session 2 and 3. It is essential to note that it was very rare for children to score lower than the expected limit from an earlier score, however, a few children scored higher than the expected range from an earlier score and this is consistent with an improvement of performance over time.

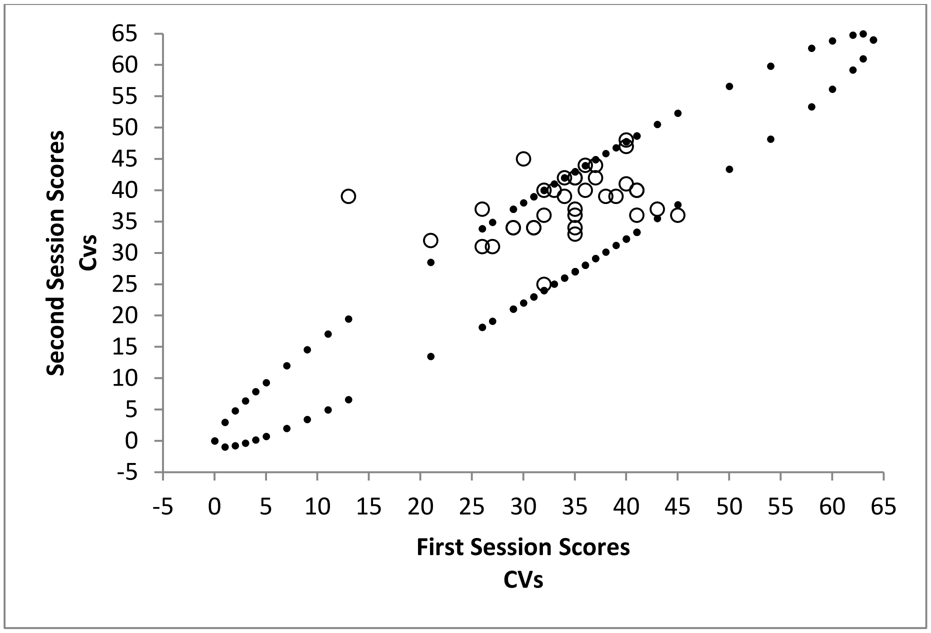


Figure 4.26: Scatter plot showing the change at individual level for CI children's CV scores from the first to the second session.

The dots represent the individual confidence intervals for session 1.

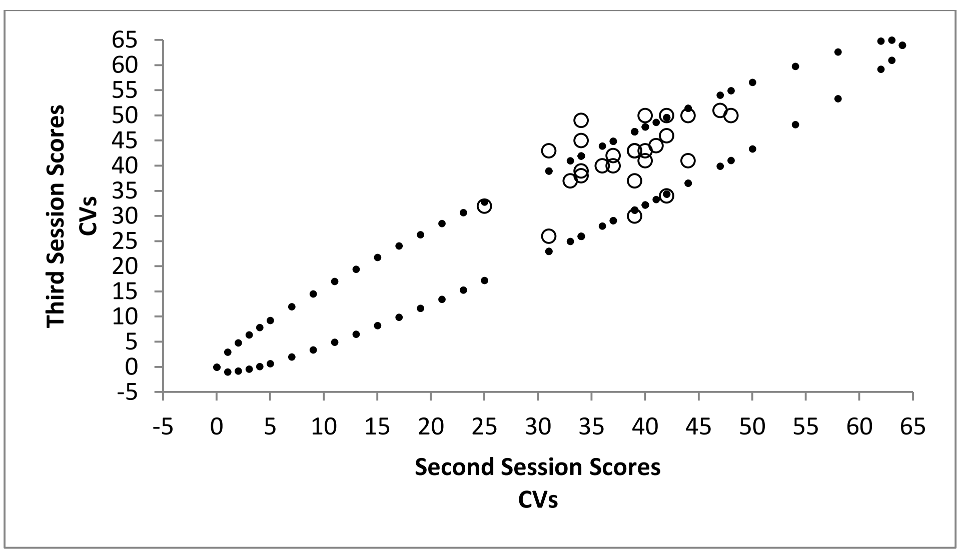


Figure 4.27: Scatter plot showing the change at individual level for CI children's CV scores from the second to the third session.

The dots represent the individual confidence intervals for session 2.

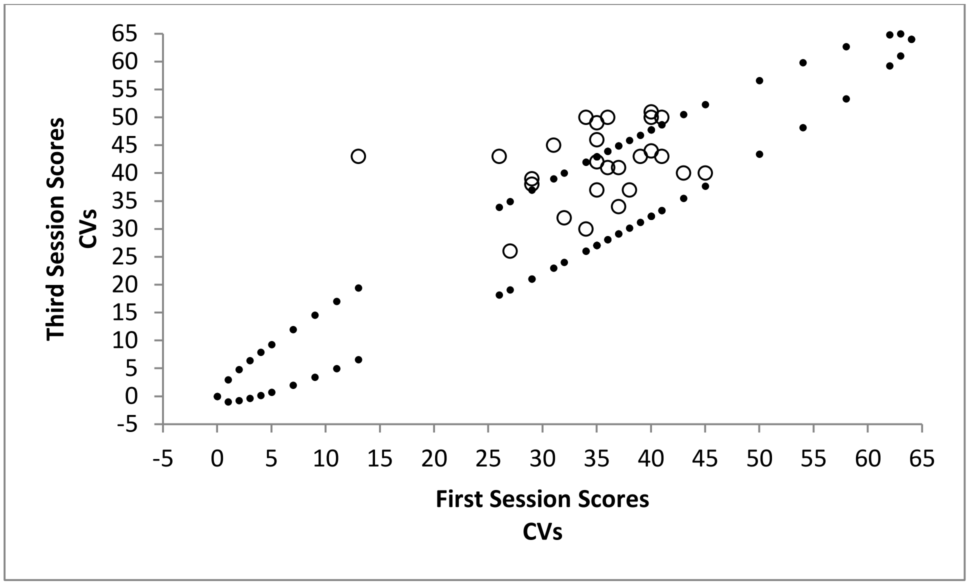


Figure 4.28: Scatter plot showing the change at individual level for CI children's CV scores from the third to the first session.

The dots represent the individual confidence intervals for session 1.

4.7.9 Effect Size of ALNT and CV scores between sessions

The effect size (Cohen's d) was calculated to determine the amount of change between sessions for the easy and hard words as well the CVs in order to compare performance on the two tests across sessions using standardized units. The average standard deviation over sessions was calculated by adding the variances over the three sessions then taking the square root of that value, and Cohen's d was calculated as the difference in score between sessions normalised to this standard deviation. The effect sizes are displayed in Figure 4.29. For the ALNT easy words from session one to session two, d=0.30 suggesting a small to moderate change in performance, while the change from session 2 to session 3 was quite small, with d=0.06, and the change from session 1 to session 3 was small to moderate, with d=0.36. For the ALNT hard words however, the effect size was small, with d=0.2 between session 1 and session 2, and d=0.23 between session 2 and session 3. The effect size between session 1 and session 3 was moderate (d=0.42). Finally, the extent of change found for the CVs from session 1 to session 2 and from session 2 to session 3 was similar and suggested that there was a small to moderate change in performance (d=0.37) however the change from session 1 to session 3 was moderate to large (d=0.74).

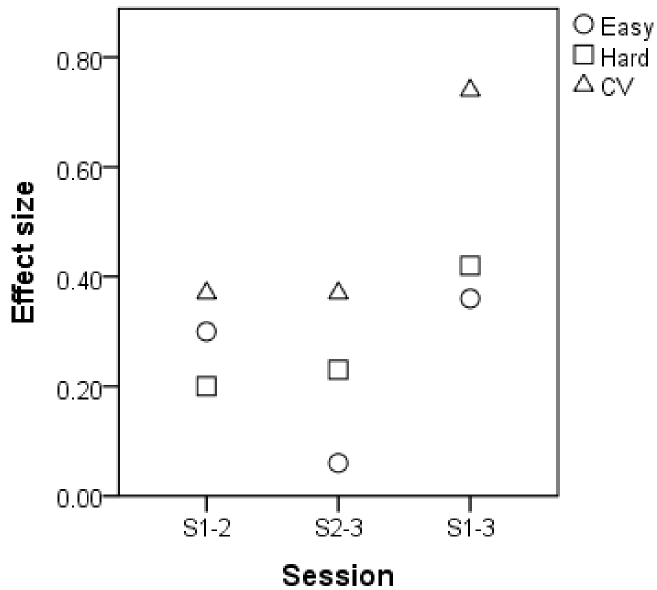


Figure 4.29: Effect size for sessions 1-2, 2-3 and 1-3 for easy and hard words, and CVs.

4.7.9.1 Multiple Regression Analysis for Lexical factors Affecting Word Recognition:

To explore which of the lexical properties (word frequency and neighbourhood density) contributed to the significant difference in scores between the easy and hard words, a multiple regression analysis was performed. The analysis included the scores of all the speech perception scores from the CI children across the first, second and third session. A hierarchical regression method (in SPSS) was used to enter the predictors into the analysis. Neighbourhood density was entered first followed by word frequency. Before conducting the regression analysis, one outlying frequency value was removed, the outcome of the analysis however was not significantly different with or without this outlier which was apparent after running the regression analysis with and without it. Neighbourhood density was a significant predictor of word recognition [$R^2 = 0.125$, $F(1,97) = 13.84$, $p<.001$] indicating that it explained 12.5% of the variance. Also, when combined together, neighbourhood density and word frequency were significant predictors of word recognition [$R^2 = 0.16.5$, $F(2,96) = 9.50$, $p<.001$] thereby explaining 16.5% of the variance. However, because neighbourhood density and word frequency were significantly inter-correlated in this set of words [$r= -.522$, $p<.001$], their effects may thus be hard to distinguish from each other. Therefore, a stepwise regression analysis was conducted to rule out the confounding effects of these two factors. The results indicated that as with neighbourhood density, word frequency was also a significant predictor of ALNT scores ($p<.001$) suggesting that word frequency and neighbourhood density both affect word recognition in Arabic children using CIs. Figure 4.30 shows that the range of scores is quite wide for words that have zero density and even though it narrows down with higher densities, it does not lead to lower scores. Additionally, the scatter plot in

Figure 4.31 shows that scores tend to be higher for words that have higher word frequencies and that they reach 100% in some words. On the other hand, scores for words with low frequencies were lower and did not reach 100%.

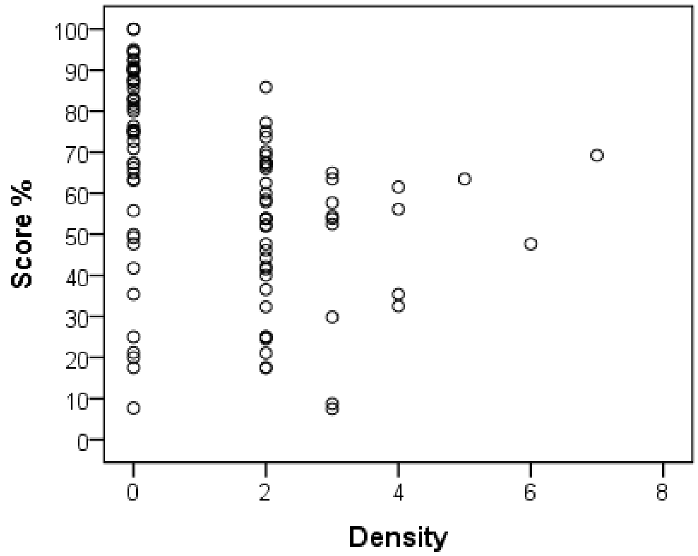


Figure 4.30: Scatterplot showing the correlation between neighbourhood density of the test words and the CI children's scores for those words in quiet.

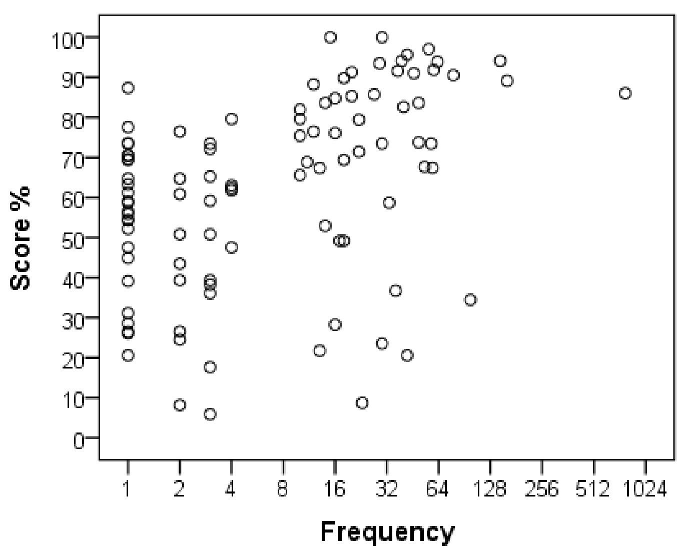


Figure 4.31: Scatterplot showing the correlation between word frequency of the test words and the CI children's scores for those words in quiet

4.7.10 Effect of familiarity with the test words on ALNT scores

In order to find out whether children with CIs were familiar with the test words, the parents of the children who participated in this study were asked to rate their children's familiarity with the test items of the ALNT. The parents were provided with a form that included all the 100 test words and were asked to note whether their child knows the word or not by ticking the corresponding box. An additional box was provided with a label that says "I do not know" in case the parents were not sure if the child knew the word or not. The parental rating of the test words took place after the third session was completed. For those children who dropped out before the third session, attempts were made to contact them by phone or email. Only ten of the 18 who dropped out before the third were successfully reached and responded by filling in the form. Appendix 7.10 shows the familiarity rating score form.

A multiple regression analysis was performed to investigate whether familiarity with neighbourhood density and word frequency affected word scores on the ALNT. Only the 36 children whom their parents completed the familiarity form were included in this analysis. A hierarchical regression method (in SPSS) was used to enter the predictors into the analysis. Neighbourhood density was entered first followed by word frequency then familiarity. Results showed that the three factors were significant predictors of ALNT scores when put together [$R^2 = 0.305$, $F(3,95) = 13.87$, $p<.001$] and explained 30.5% of the variance. Neighbourhood density by itself was also found to contribute significantly in predicting scores on the ALNT [$R^2 = 0.141$, $F(1,97) = 15.88$, $p<.001$] as did word frequency [$R^2 = 0.136$, $F(1,97) = 15.30$, $p<.001$] and each explained 14.1% and 13.6% of the variance respectively. Given that familiarity was positively correlated with both frequency [$r=.32$, $p=.001$] and neighbourhood density [$r= -.17$, $p=.04$], familiarity was also entered into the regression analysis separately to examine its effect independently. The findings revealed that familiarity did indeed have a significant independent effect on the ALNT word scores [$R^2 = 0.221$, $F(1,97) = 27.45$, $p<.001$] and thus explained 22.1% of the variance. This finding indicates that children tend to score higher on words that they are familiar with than on words that they are otherwise not familiar with. This is further confirmed by the scatter plot in Figure 4.32 below which shows that the scores are skewed to the right denoting a positive increase as familiarity increases.

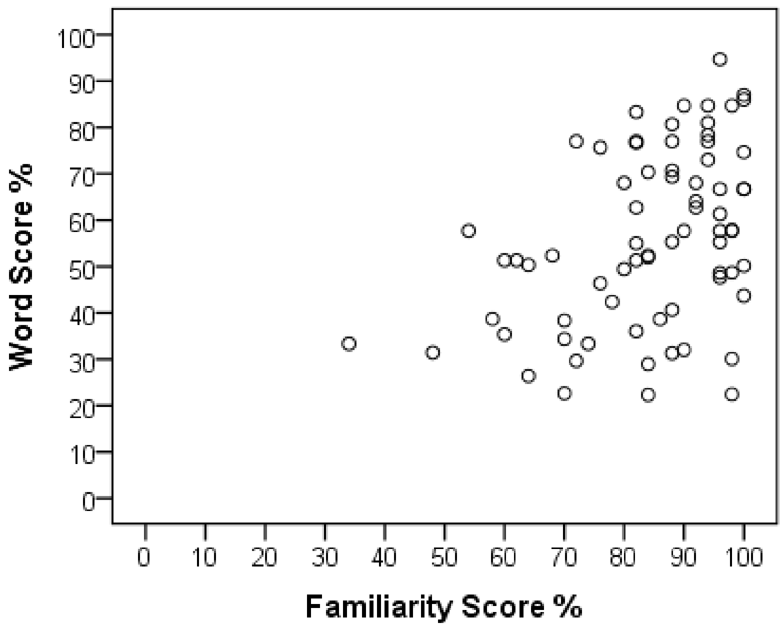


Figure 4.32: Scatterplot showing the correlation between familiarity of the test words and the CI children's scores for those words in quiet.

The effect of familiarity on ALNT scores of the same 36 children whose parents' completed the familiarity rating form was also investigated via a Linear Mixed Model Analysis (LMM). The final model included difficulty, session, and familiarity as fixed factors while subjects was the random factor. Table 4.9 displays the fixed factors included in the final model and their significance.

Table 4.9: Fixed effects included in the final model including 26 CI children for the effect of chronological age.

Fixed effects	F	Significance
Difficulty	F(1,47.82)= 141.69	p<.001
Session	F(2,30.99)= 11.60	p<.001
Familiarity	F(1,48.47)= 5.27	p=.02

The results of the LMMs revealed that familiarity had a significant effect on ALNT scores [F(1,48.47)=5.27, p=.02] which further confirms that children's scores tend to increase if they are familiar with the test words and vice versa.

In order to investigate whether familiarity differed as a function of list difficulty, a pairwise t-test was performed on the familiarity ratings between easy and hard lists. Results showed that familiarity ratings differed significantly between the two lists [t(49)= 2.61, p= .01] with the easy lists (M= 89.15, SD= 16.48) having higher familiarity rating scores than the hard lists (M= 80.18, SD= 18.08).

4.8 Discussion

4.8.1 Effect of age at implantation on word recognition

Previous research has found that age at implantation significantly affected performance on speech perception tests. So, one of the aims of the present research was to investigate whether this was true for the Arabic Lexical Neighbourhood Test (ALNT) and the CV tests. When age at implantation was included in the mixed model analysis that included all 44 children who were included in the study, it revealed an insignificant effect on performance on the ALNT. However, a scatter plot of ALNT scores against age at implantation showed a trend in which children implanted at a younger age scored higher than children who were implanted at a later age (See Figure 4.1 and 4.2). Another mixed model analysis was performed only on the 26 children who completed all three sessions. This analysis was performed because it was suspected that it would be more powerful and comparable to other studies given that all children have completed the test protocol in all three testing sessions which would make the analysis more balanced. The findings of this second analysis revealed that age at implantation did indeed have a significant effect on performance on the ALNT. This finding is consistent with previous studies which investigated the effect of age at implantation on speech perception skills (Kirk et al., 2002; Manrique et al., 2004; Svirsky et al., 2004; Wu, Lin, Yang, & Lin, 2006). However, it is not consistent with those findings found in a recent study by AlSanosi and Hassan (2014) examining the effect of age at implantation on Saudi children with cochlear implants. AlSanosi & Hassan tested 67 children on measures of expressive and receptive language as well as speech perception skills over a 24 month period. The children were divided into two groups based on age at implantation. Group 1 were implanted under 5 years and Group 2 were implanted above 5 years of age. Their findings revealed no significant difference between the two age groups on measures of language and speech perception skills. They attributed this insignificant age effect to the short follow-up period. An interesting fact about Alsanosi & Hassan's study and the present study is that there is overlap in some of the children who were tested in their study and in the current study as both studies were conducted in the same hospital. However, many differences are found in the methodology of the two studies. For example they tested age as a categorical variable and used different cut-offs for grouping the children while we used age as a continuous variable in our analysis. Another difference concerns the materials used for speech perception testing in that the speech perception tests used in AlSanosi & Hassan's study were a translated version of the English Tests whereas the current study used words selected from a corpus in Arabic language. The trend that is consistent with the effect of age at implantation in the current study may have been due to these methodological differences. This may also indicate that tests developed in the language of interest may be more accurate in measuring speech perception skills than translated tests and not using strict cut-offs for age may provide a better picture of individual variability.

When the effect of age at implantation on the CVs was investigated however, it was found to be insignificant. The CV test is different from the word recognition test in that it is independent of cognitive and lexical factors; children do not have the opportunity of linking what they heard to any previously acquired information. Therefore, performance on the CV test is basically related to how well speech signals are processed by a cochlear implant (CI) rather than the age at which CI occurred which may be the reason why CV scores were not significantly correlated with age at implantation. This result is consistent with a study in Mandarin Chinese by Wu and Yang (2003) who investigated the effect of implantation age on several speech perception tests in children using CIs one of which was the Chinese consonant test which included 21 consonants in the form of CV/CVV. Their findings revealed that improvement in performance on the consonant test was not correlated with age at implantation however reasons for this finding were not justified.

The advantage of early implantation seen here supports the notion that early implantation yields a shorter period of sensory deprivation and takes advantage of the increased auditory neural plasticity phase and that this plasticity gradually decreases as children get older (Kral & Sharma, 2012).

4.8.2 Comparison of performance on ALNT with CVs test

As previously mentioned, there are no available standardized tests to which the ALNT can be compared. Hence we developed a nonsense syllable test to use as a reference for performance on the ALNT. An advantage of such a test is that it is independent of linguistic knowledge and is designed based on the phonemes of the language of interest. These qualities make it suitable to be developed in any language. The CI children's scores on the CVs revealed that performance improved significantly across all three sessions. When performance on the ALNT was compared to performance on the CVs, the amount of change from one session to the other on the CVs was moderate but slightly higher than that on the ALNT which indicates that the sensitivity of the CVs in measuring change in performance is slightly higher than the sensitivity of the ALNT.

4.8.3 Effect of duration of implantation on word recognition

The effect of duration of implantation was also investigated in relation to scores on the ALNT and CVs. However, no effect of duration of implantation was found on either test, suggesting that children with less experience are doing as well as children with more experience. Reasons for these findings could be due to the small number of subjects within each time frame for each session. This is true especially for the longer durations of device use (i.e. beyond 5 years). It could be that a larger number of subjects with longer periods of implant use may yield a significant effect on the ALNT. Another explanation could be that extra experience with an implant may not lead to a significant difference in speech perception skills (Sarant, 2001). More than 50% of the children included in this study had more than 4 years of experience with their implant system, and the studies that have shown the effect of duration of implantation often compared children with 3 to 4 years of experience with those who had experience of less than 3 years (Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004; Zwolan et al., 2004). Nevertheless, inspection of the scatter plot (Figure 4.3 and 4.4) of duration against ALNT score does show a slight tendency for improvement in speech perception scores with an increase in device use.

The statistically insignificant findings of the present study are in accordance with findings of Swami, James, Sabrigirish, Singh, and Ohal (2013). Swami and colleagues studied the effect of several factors on audiological and speech and language outcomes in paediatric cochlear implant users one of which was duration of implant use. Speech perception was assessed by the Meaningful Use of Speech Scale (MUSS); a parent reported scale via an interview format. The findings revealed that there was no significant effect of length of implant use on improvement in speech perception on the MUSS. The authors attributed this finding to the short duration of study (2 years). Other studies which have investigated the effect of length of implant use on speech perception however, have positive correlations between duration of implant use and outcome measures (Beadle et al., 2005; Dowell, Dettman, Blamey, Barker, & Clark, 2002; Geers, Nicholas, et al., 2003; Liu et al., 2013; Waltzman, Cohen, Green, & Roland Jr, 2002).

The fact that the children in the current study did not show an effect of duration of cochlear implant use on speech perception performance suggests that speech perception performance on the ALNT and CV tests is independent of duration of use of device, implying that experience with the implant is not required for the formation of neural networks or connections to auditory input in the brain. However, because children usually require rehabilitation post cochlear implantation in order to develop their speech and language skills, the insignificant effect found in the current study may be due to the small number of children in each time frame for the duration factor or due to the type of stimuli that was chosen for the ALNT. Therefore, the effect of duration may be apparent with the use of different assessment materials and with a larger number of children.

4.8.4 Chronological age

This factor was investigated to discover whether development of speech and language over the testing period had an effect on speech perception performance on the ALNT and CVs. However, the effect of chronological age was insignificant indicating that any improvements on the ALNT and CVs were not influenced by speech and language development. This finding is essential as it shows that improvement was mainly due to improvement in speech perception skills.

4.8.5 Effect of lexical factors on word recognition

Another aim of the present study was to examine whether the lexical properties of word frequency and neighbourhood density affected word recognition in children using CIs. These results are consistent with previous studies which investigated the effect of these lexical factors on children with CIs (Kirk, 1995; Yuen et al., 2008; Yang & Wu, 2005; Wang et al., 2010; Liu et al., 2013). Moreover, these findings are consistent with the view that Arabic-speaking as well as English-speaking children organize words in their mental lexicon according to “similarity neighbourhoods” (Luce & Pisoni, 1998) and that this finding applies both to normal hearing (NH) Arabic children and children with CIs.

A study by Bouton, Colé, and Serniclaes (2012) examined the effect of lexical knowledge on speech perception in 6 year old French CI and NH children who were matched for listening age. The stimuli used in their experiment included both words and pseudo words. They hypothesized that CI children rely on lexical information to a greater degree than NH children for phonetic feature identification because they perceive these features with less accuracy. Results showed that CI children scored lower than NH children on feature perception in both words and pseudowords, however scores on words were higher than scores on pseudowords. This was attributed to the acoustic limitations of the CI signal processing. The effect of lexical knowledge on feature perception was calculated by the difference between scores on words and pseudo words for both CI and NH children separately. The difference was similar between the two groups of children. The improved performance in feature perception in words led the authors to conclude that CI children use their lexical knowledge as a compensatory mechanism for feature discrimination in a similar way to NH children, but that they tend to rely more heavily on this mechanism than NH children and that the acoustic information provided via the CI allows the use of lexical information for word recognition. Consequently, if they did not rely on lexical knowledge, the feature perception scores would be similar in both pseudowords and words. It may also be that phonotactic probability played a role in the identification of words in that simply identifying a few phonemes of the target word would have assisted in identifying the whole word. This explanation may also be applicable to the current study in that the easy words may have been easier to recognize for reasons that were non-lexical such as their phonotactic structure, and that recognizing a few sounds from these words is enough to identify the words correctly. A final explanation for the increased scores on the easy words than on the hard words could be related to familiarity of the test words. The finding that familiarity ratings of the easy word lists were significantly higher than the hard word lists may have been the reason for the difference in scores between the easy and hard lists. This familiarity factor could be overcome in future studies by ensuring that test items in both easy and hard lists are all known to the children being tested in order to rule out the familiarity effects.

To discover which of the lexical properties (word frequency or neighbourhood density) accounted for word recognition on the ALNT, a multiple regression analysis was conducted. The analysis revealed that both neighbourhood density and word frequency played a role in lexical access. These relationships are stronger than those found in chapter 3 when these lexical effects were examined in NH children and are in line with the English and Chinese studies which reported that both neighbourhood and word frequency had an effect on word recognition (Dirk's et al., 2001; Liu et al., 2011). The familiarity factor was also added to this regression analysis and was found to have a significant effect on word scores which further stresses the importance of utilizing speech perception measures that contain familiar items to children being tested otherwise their test scores will be inaccurate and may not reflect their true performance.

On an individual level, the percentage of children who improved over time beyond the random change expected from binomial variability for easy words was 11% (session 1 to 2), 11.5% (session 2 to 3) and 27% (session 1 to 3). For the hard words these percentages were 30.5%, 11.5%, and 35% respectively. Thus, the hard words seem more sensitive to improvement over time than the easy words. When compared to individual results on the CV test, 22% of children improved from session 1 to session 2, 27% improved from session 2 to session 3, and 46% improved from session 1 to session 3. This suggests that the CV test is more sensitive to change in performance between sessions than the ALNT. It is noteworthy that the difference between easy and hard word scores for the CI children in this experiment is 22% in the first session, 24% in the second session, and 17.5% in the third session. These differences are 3.5 to 14% higher than those observed for the NH children in Chapter3. According to Eisenberg et al. (2002) the larger the gap between easy and hard words scores the more likely it is that discrimination is dependent on broad phonetic features (e.g. words withv high frequency and low confusability at the phonemic level) rather than fine phonetic cues. An alternative explanation for this enlarged gap being only present in the CI group in the first two sessions might be the unfamiliarity of the children with the testing procedure provided in the current study as it was the first time that they had completed a speech perception test via recorded stimuli. However the smaller effect of difficulty in the third session is also likely to be affected by the presence of ceiling effects for the easy words in this session. It is of course also likely that the NH children were also unfamiliar with the testing method on their first session and it seems reasonable to accept that the CI children in this study are likely to be using broad rather than detailed phonetic cues in the ALNT task.

4.8.6 Neighbour errors versus non-neighbour errors

The children's errors on the ALNT were further analysed to compare the number of errors that were neighbours to those which were non-neighbours of the target word. It was found that the number of the errors that were not neighbours were significantly higher than the errors that were neighbours for both the easy and hard words. Furthermore, the percentage of errors that were neighbours was higher for the hard words than the easy words while the errors that were not neighbours were higher for the easy words. These results are in accordance with how the test was constructed where the hard list had higher neighbourhood density than the easy list and consequently the children generated more neighbours for the hard words than that for the easy words. Given the low number of neighbour errors, this may be an indication that the Neighbourhood Activation Model (NAM) may not be a suitable model of lexical effects in

Arabic language. However a variety of the NAM that defines neighbourhood density differently may fit the data better.

4.8.7 Comparison of normal hearing children and children using CIs

The present study also explored the performance of children with CIs in comparison to age-matched NH children listening to CI simulations. It is clear that these implanted children receive more information than that provided by a 4 channel CI simulation as scores with an 8 channel simulation were broadly in line with the results of the implanted children. This may indicate that the use of 4 spectral channel simulations might be underestimating hearing abilities of children using CIs. CI children's performance was comparable to NH children with 8 spectral channels on easy words but not on hard words which may indicate that when fine discrimination skills are required, CI children's performance may decrease to a level that is comparable to a NH child with 4 spectral channels.

The results of our study are congruent with those of Eisenberg et al. (2002), who compared the performance of CI children with that of NH using 4 spectral channels. Similar to the current study, their findings demonstrated that the performance of CI children was better than the performance of NH children in the vocoded speech condition.

4.8.8 Effect of repetition of ALNT test items

For the ALNT test to be used as a clinical tool, repeated administration of the test will be required to assess children longitudinally. Therefore we examined the effect of repetition of test items 3 times over an 18 month period. For both easy and hard words, there was no effect of repetition between sessions 1 and 2 or sessions 2 and 3. This suggests that the test lists can be presented repeatedly at different test intervals without learning affecting performance. The current results differ in this respect from those with NH children in the previous chapter, but there the interval between repeated tests was 2-4 weeks rather than 6-9 months.

4.8.9 Clinical suitability of the ALNT

An essential aim of this study was to determine the feasibility of the ALNT as a clinical tool for measuring speech perception skills. The test was applied on CI children over 3 sessions with 6-9 months intervals. It proved feasible to use the ALNT with children with CIs. The children were easily able to comprehend the test instructions and were able to complete the test protocol without fatigue. Analysis of the test results across the three sessions revealed that group scores improved significantly from session one to session three. This indicates that that the ALNT is able to measure progress over time and in this is comparable to the English LNT (Cohen, Waltzman, Roland Jr, Staller, & Hoffman, 1999; Geers, Tobey, Moog, & Brenner, 2008; Waltzman, Scalchunes, & Cohen, 2000). Cohen et al. (1999) followed up a group of 19 CI children up to 1 year post implantation. They used a range of speech perception tests for evaluation, two of which were the Lexical Neighbourhood Test (LNT) and the Multisyllabic Lexical Neighbourhood Test (MLNT). The LNT and MLNT were applied preoperatively and 3 and 6 months postoperatively. Results revealed that there was significant improvement in speech perception overtime. Another study by Geers et al. (2008) used the LNT to determine progress over time in 85 subjects. The subjects were tested twice, once in elementary school (age 8-9 years) and once in high school (age 15-18 years). Improvement in speech perception from the first test occasion to the second was significant.

In clinical use, the authors of the LNT declare that it can assist in providing diagnostic information by assisting in discovering the extent to which children with CIs are able to make fine-grained acoustic-phonetic discriminations between words; i.e., if children who score extremely low on hard words compared to easy words, this may suggest that they lack the ability to encode the fine acoustic information present in the speech signal (Kirk et al., 1998). Another method for utilizing the test scores could be for rehabilitative purposes where therapy sessions could focus training on minimal pairs (i.e. words differing by only one phoneme) in order to increase fine-grained acoustic phonetic discrimination skills.

4.9 Conclusion

The aim of this study was to administer the ALNT on children using CIs to evaluate its clinical feasibility for assessing word recognition skills and more generally, to discover whether lexical properties have an impact on word recognition in CI users. After applying the ALNT three times over a period of 18 months, overall results showed that the ALNT is suitable for assessing word recognition in CI children. However, although the fact that these children scored higher on easy words rather than hard words implies that the lexical factors of word frequency and neighbourhood density influence word recognition, the finding that children’s performance increased with familiarity of the test words and that familiarity ratings were significantly higher for the easy words than the hard words indicates that lexical factors may not be the sole predictors of difference in performance between easy and hard words. The ALNT was also able to measure progress over time however its sensitivity to measuring change was lower than the CV nonsense syllable test. Finally, though age at implantation and familiarity were significant predictors of performance on the ALNT, effects of duration of device use, and chronological age were not significantly correlated with scores on the ALNT.

5 Chapter five: Sequential information transfer analysis

5.1 Introduction

The analysis of perceptual confusions was used by Miller & Nicely (1995) in an attempt to explore the type of confusion errors that occur in the perception of phonemes as well as their most important features. In order to do this, they examined the perceptual confusions of 16 English consonants when presented with frequency distortion or noise. Their results showed that place was more affected than voicing and nasality by low-pass filtering and noise. Following this approach, the perceptual confusions of all the children's responses (i.e. normal hearing children in noise and vocoded speech as well as children with cochlear implants) were analysed to discover which features were affected the most and to find out if there were certain phonemic features that were responsible for the making the easy words easier to recognize and the hard words more difficult to recognise.

5.2 Sequential information transfer analysis (SINFA) of children's productions

In addition to error analysis, the FIX (Feature Information Xfer) program was used to analyse confusion matrices of children's responses (same children included in the error analysis) by sequential information transfer analysis. The FIX is a software package produced by Mike Johnson of the Department of Phonetics and Linguistics, University College, London; it is available from http://www.phon.ucl.ac.uk/resource.This analysis allows the description of consonant and vowel recognition based on the amount of information transfer from stimulus to response for a set of phonetic features thereby assisting in identifying the features that play the highest role in word recognition. Questions addressed by such an analysis include whether or not feature perception for vowels and consonants are different between easy and hard lists and across the different groups of children; does feature perception vary across positions within words (i.e. is there any position in particular where feature perception might be too difficult). If feature perception differs between easy and hard words and certain features appear to be more difficult to perceive than others then this could indicate that non-lexical effects may have played a role on the difference between easy and hard word scores. Figures 5.1, 5.2, 5.3, and 5.4 demonstrate the amount of input information (bits) as well as the proportion of the information received by the NH children during testing in two conditions: noise and vocoded speech in addition to children using cochlear implants. Appendix 7.11 displays the confusion matrices used for the SINFA analysis as well as the first iteration output for each matrix.

The vowels were coded for the features of Place, Height, and Duration whereas the consonants were coded for features of Voice, Place, Manner, and Duration. From Figure 5.1, it can be seen that for the vowels, the height feature mostly had the highest input information indicating that it had a larger range of response choices across all three groups of children in both first and second word positions of easy words and the second position of the hard words followed by duration and place. The difference between easy and hard words is that in general the input information for the different features is slightly lower in the hard list and particularly the first position in the hard words where no information for place is available. The proportion of information received by the children during testing is highest for the duration feature in both the first and second positions of easy and hard words across all three groups of children except for the second position of hard words for children in the noise condition where place is slightly higher than the duration feature.

Despite all this, it is unlikely that children would depend solely on durational cues to identify vowels especially that coding for duration is binary. While most of the input information is from the height feature, it would be expected that height and duration were correlated with one another in these vowels. Confusion matrices demonstrate that vowels that are both high and long in duration are identified with high precision in both CI and NH children. It is interesting to note that children using CIs tend to receive more information from place and height in the vowels in the easy words than NH children in the other conditions (noise and vocoded speech). In the vowels of the hard words however, children with CIs and children in the vocoded speech condition seem to follow a similar pattern.

For the consonants, place was the feature that had a larger range of response choices in all four word positions when compared to the remaining features for both easy and hard words followed by manner and duration. When looking at the proportion of information received by these children from the consonants (Figure 5.2), feature patterns were more or less the same from one group to the other and across easy and hard words. However, the children in the vocoded speech condition seem to be receiving less information about duration in the final word position of both easy and hard words but this is more prominent in the hard words. This might be related to how signals are processed with noise vocoders especially that children with CIs resemble NH children in the noise condition for this particular feature in the final position. The main difference between easy and hard words' input information is that there is no information for the duration feature in the third position. Unlike the vowels, the proportion of information received is quite similar across features for all the three groups indicating that all these features may not be independent of each other in the word identification process.

The responses of the CI children on the CV test were also analysed. Compared to the vowels in the first position of words, the CV input information for vowels (Figure 5.3) was similar to that observed in the hard words in that only information available from height and duration are available. The height and duration features were quite similar in the amount of input information for vowels but for the amount of information received by children, the height feature was slightly higher than the duration feature. For the consonants (Figure 5.4), the pattern of information for the different features was similar to that seen in the first position of easy and hard words. Place was the dominant feature in input information and duration was the dominant feature for the proportion of the transmitted information. This indicates that the consonants chosen for the CV test cover a range that resembles the consonants found in the easy and hard word lists.

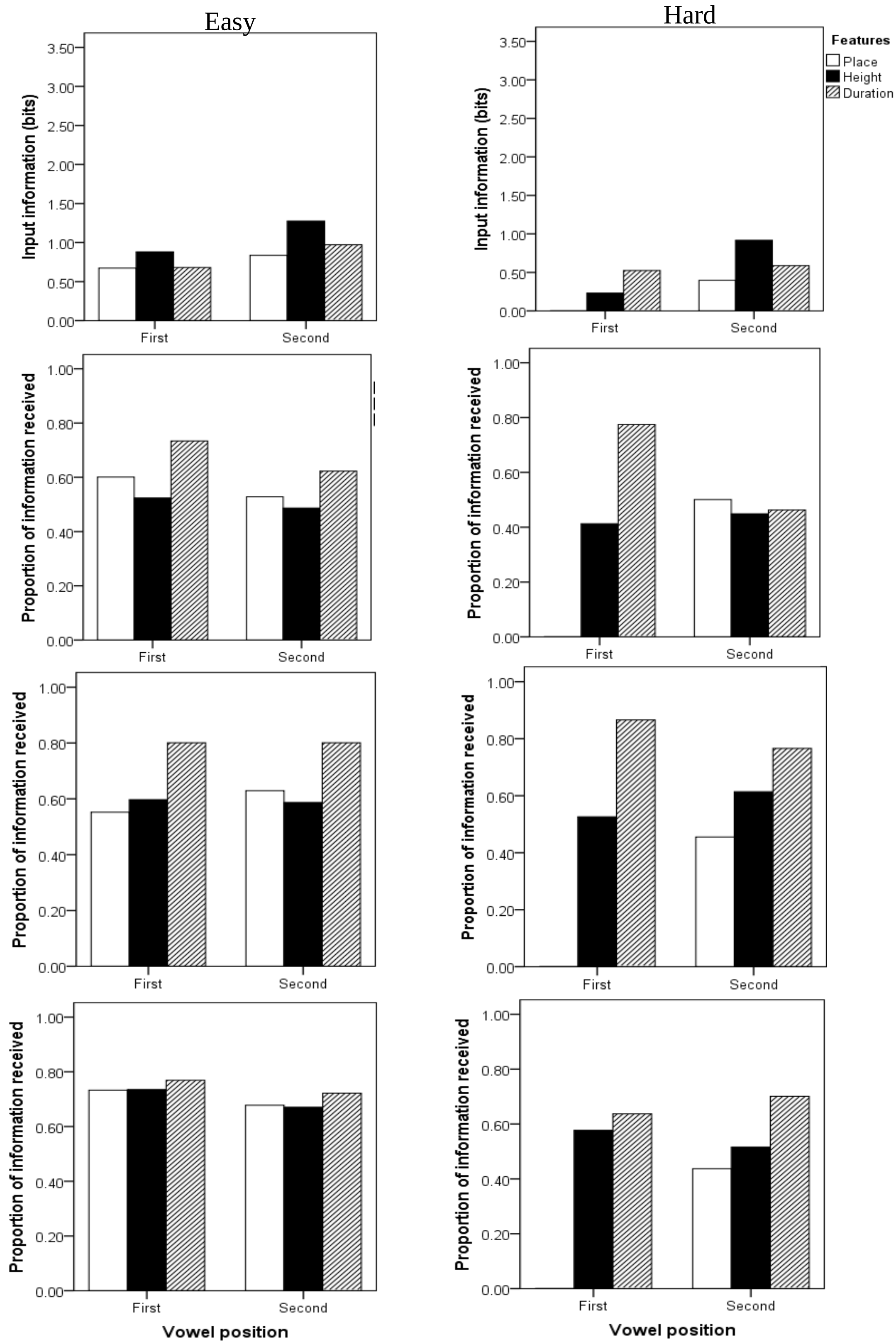


Figure 5.1: Input information (top panel) and proportion information received from easy vowels (left panel) and hard vowels (right panel) based on sequential information transfer analysis (SINFA) for NH children in noise (second panel), vocoded speech (third panel), and CI users (fourth panel)

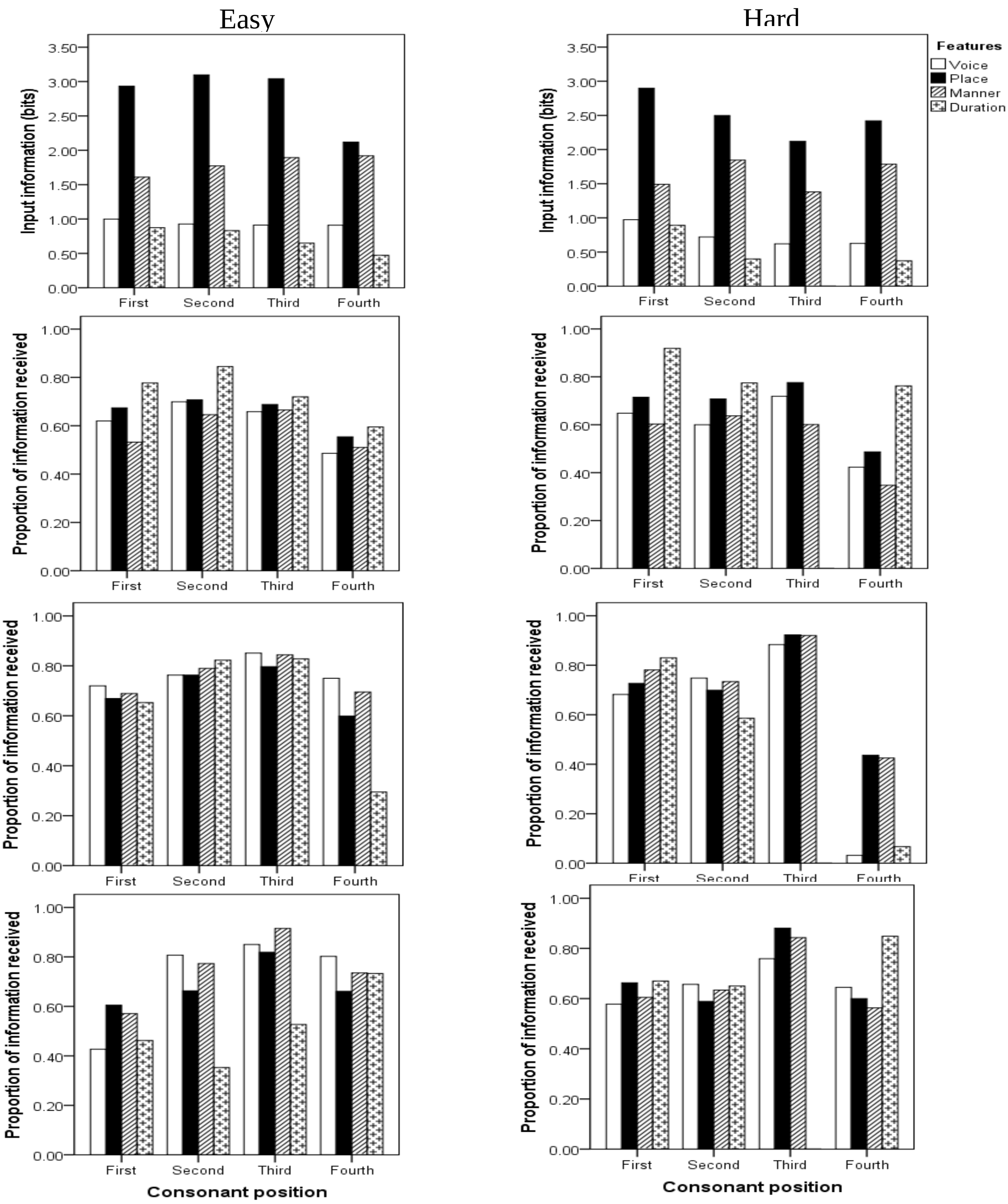


Figure 5.2: Input information (top panel) and proportion information received from easy consonants (left panel) and hard consonants (right panel) based on sequential information transfer analysis (SINFA) for NH in noise (second panel), vocoded speech (third panel), and CI users (fourth panel).

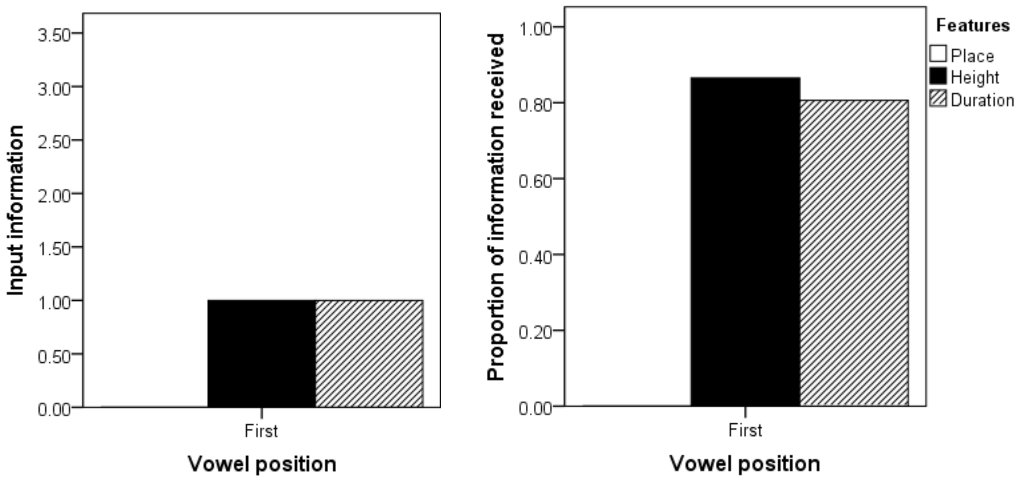


Figure 5.3: Input information and proportion information received from the vowels of the CV test based on sequential information transfer analysis (SINFA) in children using cochlear implants.

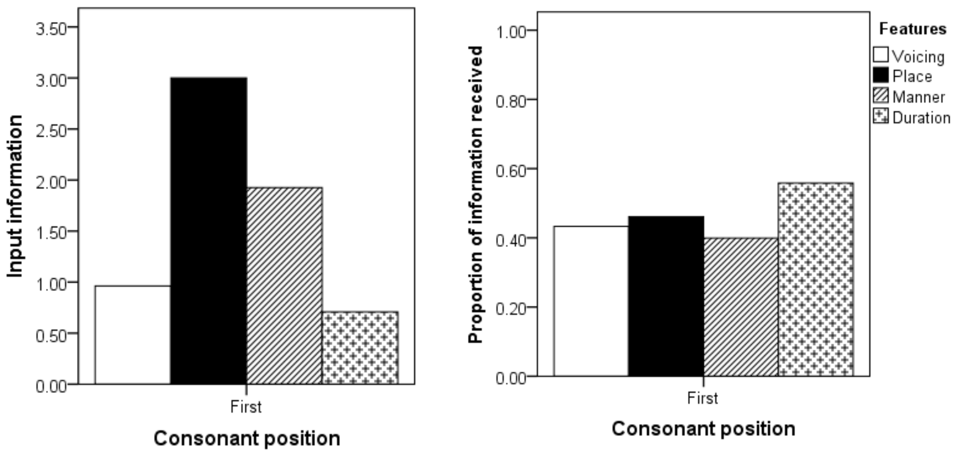


Figure 5.4: Input information and proportion information received from the consonants of the CV test based on sequential information transfer analysis (SINFA) in children using cochlear implants.

5.4.3. Phoneme scoring for easy and hard words

In previous investigations of the effects of lexical factors (word frequency and neighbourhood density) on word recognition, phonetic scoring was conducted in addition to whole word scoring in order to find out whether phonetic cues had an impact on word recognition (Kirk et al., 1995; Yang, Wu, Lin, & Lin, 2004; Yuen et al., 2008). In the current study, phoneme scoring was conducted for ALNT responses of NH children in both noise and vocoded speech conditions as well as children using CIs. For the NH children in noise condition, a pairwise t-test revealed that phoneme scores did not differ between easy words (M= 73.16, SD= 6.68) and hard words (M= 74.35, SD=6.68) with $t(23)=-.99$, ($p=.33$) (Figure 5.5.). Similarly when phoneme scores were calculated for the NH children in the vocoded speech condition, pairwise t-tests showed no significant difference between easy words (M= 71.04, SD= 6.74) and hard words (M= 72.81, SD=8.04) in the 4 channel number condition ($t(23)=-1.06$, $p=.29$) nor between the easy words (M= 92.52, SD= 3.52) and hard words (M= 89.30, SD=6.78) in the 8 channel number condition ($t(23)=1.77$, $p=.08$) (Figure 5.6). However, when phoneme scoring was conducted for children using CIs, the pairwise t-test showed that the easy words (M= 81.47, SD=9.48) had significantly higher phoneme scores than the hard words (M= 75.39, SD=13.51) with $t(25)=4.56$ and ($p<.001$) (Figure 5.7).

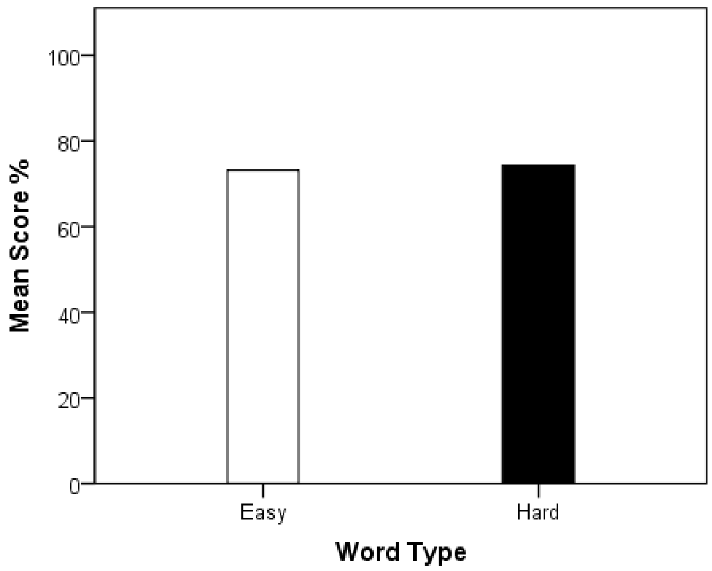


Figure 5.5: Bar chart displaying the mean percent phoneme scores for easy and hard words for NH children in the noise condition.

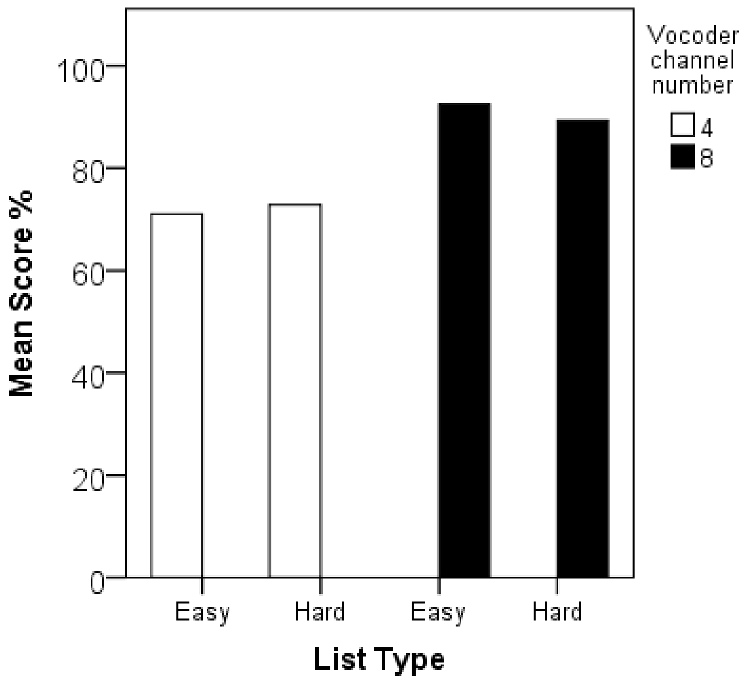


Figure 5.6: Bar chart displaying the mean percent phoneme scores for NH in vocoded speech condition via 4 and 8 channel numbers.

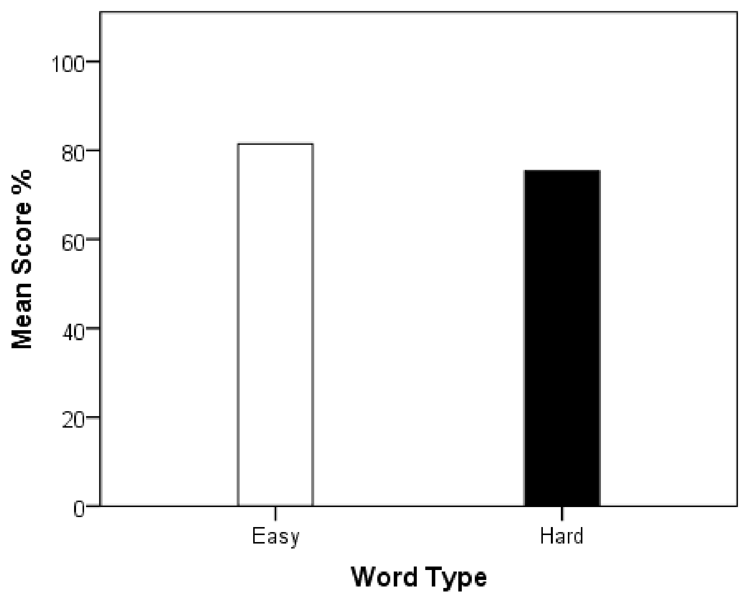


Figure 5.7: Bar chart showing the phoneme percent scores of the easy and hard words for the children with cochlear implants.

The results of the NH children are consistent with the results of Kirk et al. (1995) whereby no difference in phoneme scoring was found between the easy and hard words. According to Kirk, this finding demonstrates that children do not identify words on a phonemic basis but rather on a lexical basis because if they did identify words on a phonemic bases then both phoneme and word scores would show the same effect of difficulty. The current findings for NH children are consistent with Kirk's findings, with word scores for easy words being significantly higher than for hard words whereas phoneme scores for easy and hard words were not significantly different. In the children using CIs however, this was not true. Their phoneme scores for the easy words were significantly higher than the phoneme scores for the hard words. This seems consistent with the error analysis reported above whereby the CI children had fewer neighbour errors than the NH children, suggesting a role for factors other than neighbourhood density. When relating this finding to the NAM, it is possible that neighbourhood density needs to be defined differently in CI children. In other words, due to the degraded signal provided by CIs, children using CIs will perceive speech sounds with reduced phonetic detail whereby certain different sounds may be perceived as identical if some phonetic features are not distinguishable to them auditorily. Based on this, words will be grouped into similarity neighbourhoods in a manner that is different from that in NH children and will consequently be stored differently in the mental lexicon. This is very important as it may indicate that in Arabic at least a different definition for neighbourhood density may be required for CI users.

In order to further investigate whether phonetic cues had an impact on word recognition on the ALNT, Pearson product moment correlations was performed on the easy, hard and CV scores for children using CIs. Results showed that there was no significant correlation between the easy scores and the CV scores [r=0.24 and p=0.10] or between the hard scores and the CV scores [r=0.03 and p=0.83] implying that word performance on the ALNT was not affected by phonetic cues.

It is unlikely that this is due to children's unfamiliarity with the test words because parental familiarity ratings showed that they were familiar with at least 80% of the words indicating that this was not the reason for the distinctive phoneme results for these children. Figures 5.8, 5.9, 5.10, and 5.11 below show the test words and the percentage of familiarity for each word. It is obvious from these figures that children are familiar with more words in the second easy list and the first hard list than the other two lists. As mentioned earlier in chapter 2, the easy words and the hard words were divided into two equal lists based on NH children's scores and given the different spread of ratings between the two lists, this may signal that using NH children's scores may not be the best method to do this. Therefore, the test words may need to be regrouped based on CI children's needs.

Since performance of CI children on the ALNT increased with increased familiarity with the test words, it could be one of the reasons for the significant difference between the easy and hard word scores in addition to the lexical factors especially given that its contribution to performance on the ALNT was higher than both neighbourhood density and word frequency. This could be investigated in the future by controlling for the familiarity factor when examining the effects of lexical factors.

In general, feature analysis did not reveal any differences between the easy and hard word lists but phoneme analysis and familiarity ratings did. Thus, it may be necessary in future tests to control these two latter factors in order to ensure that results reflect the effects of the lexical factors of word frequency and neighbourhood density without the interference of other factors.

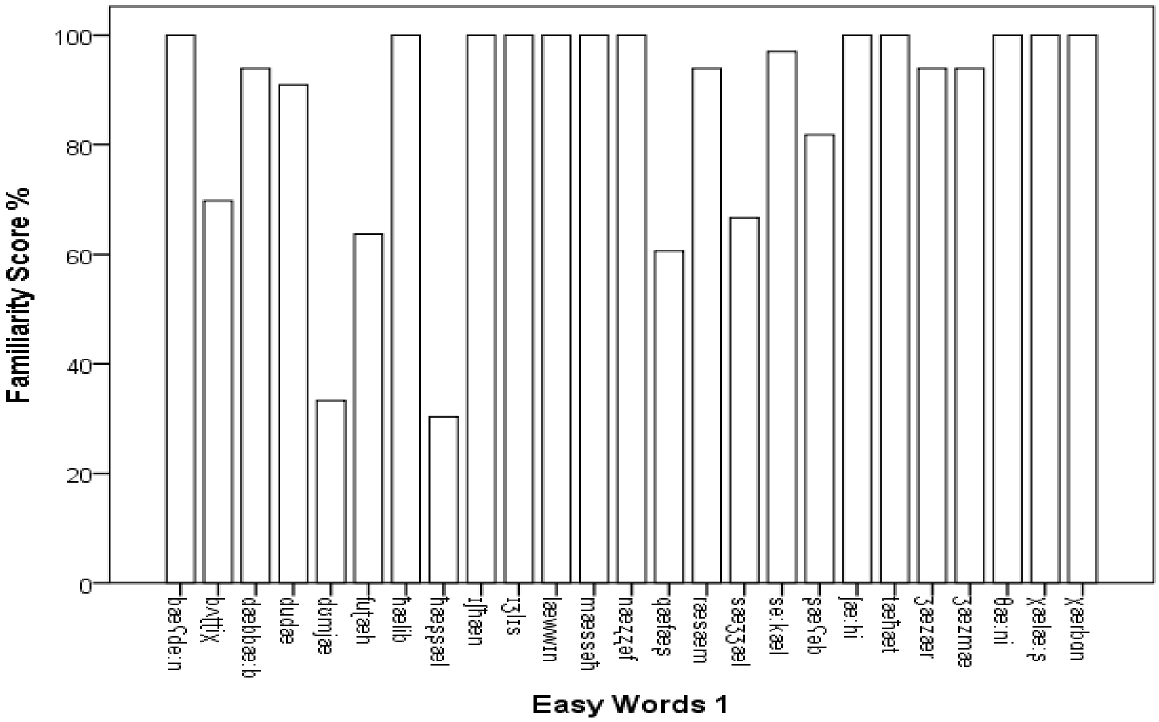


Figure 5.8: Bar chart displaying familiarity ratings in percentages for easy words in list 1.

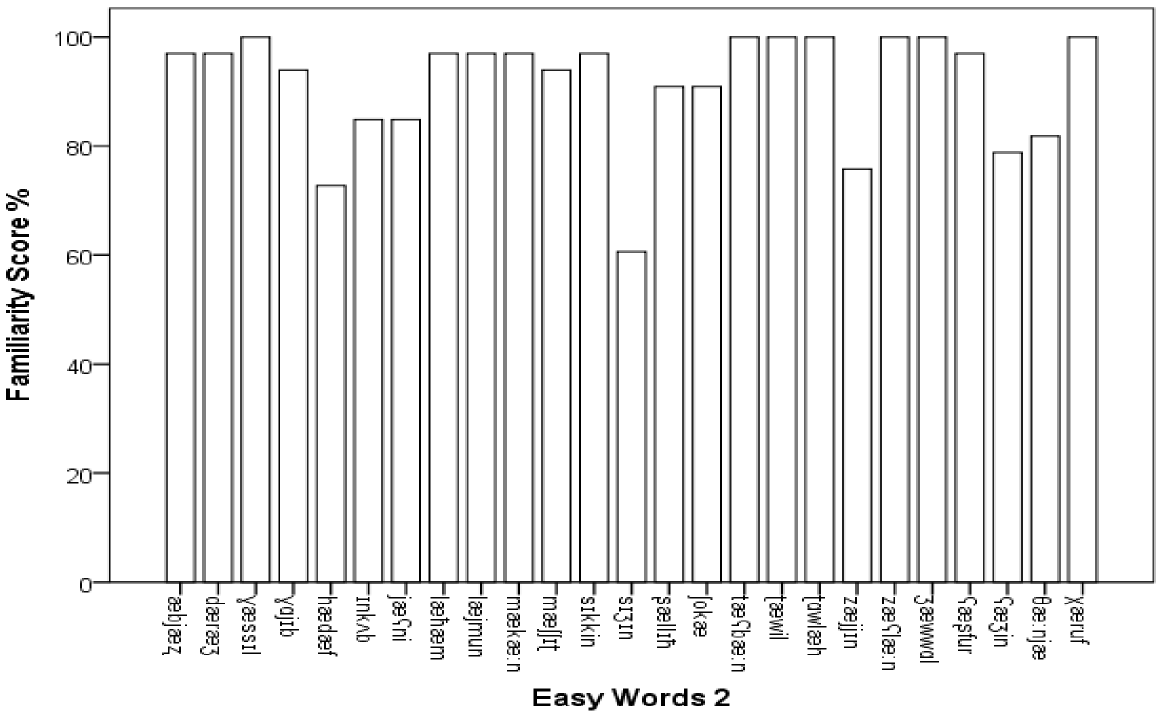


Figure 5.9: Bar chart displaying familiarity ratings in percentages for easy words in list 2.

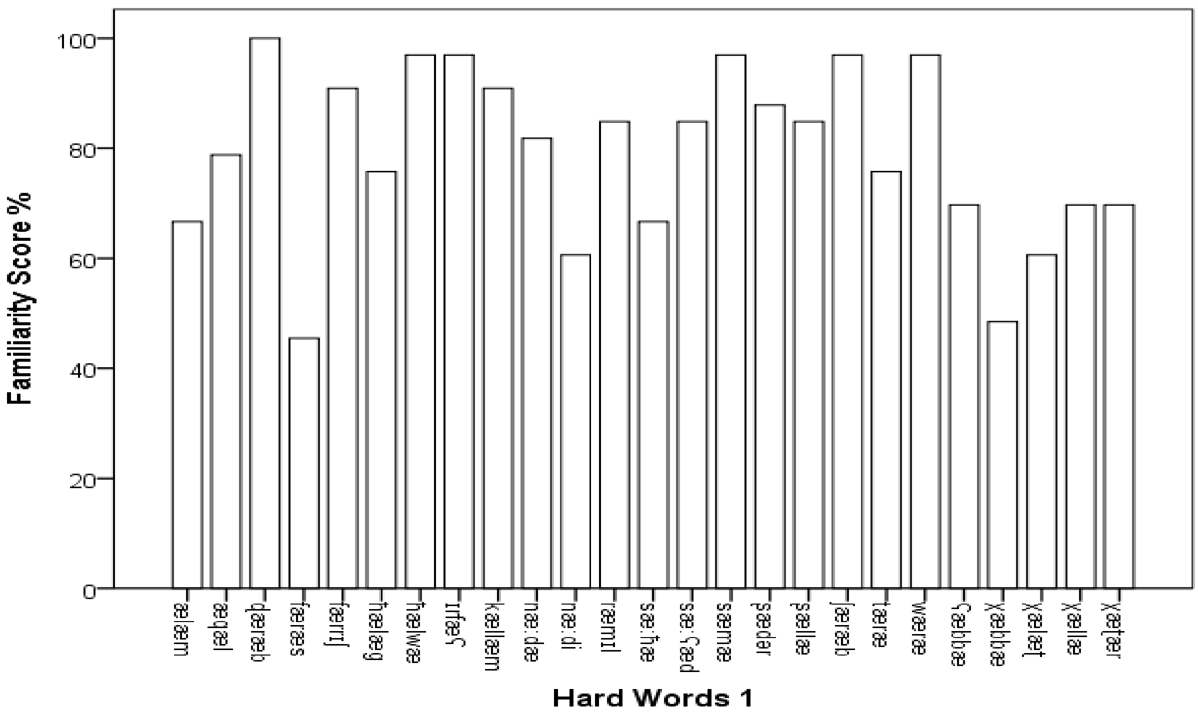


Figure 5.10: Bar chart displaying familiarity ratings in percentages for hard words in list 1.

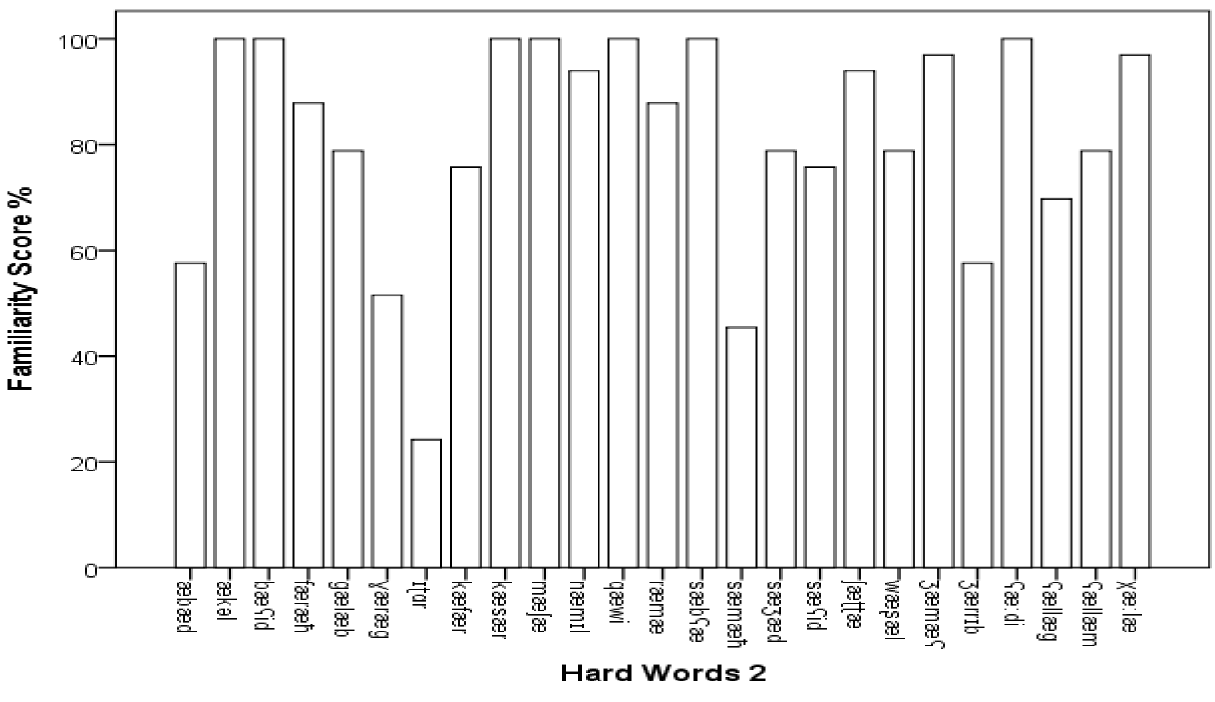


Figure 5.11: Figure 5.11: Bar chart displaying familiarity ratings in percentages for hard words in list 2.

6 Chapter six: General discussion

6.1 Development of the Arabic Lexical Neighbourhood Test (ALNT)

Generally speaking, the development of a speech perception test that controls for the lexical factors of word frequency and neighbourhood density in a way that resembles the English Lexical Neighbourhood Test was achievable in Arabic language despite the major differences between English and Arabic. There are some issues that have arisen in the development of the ALNT and these should be addressed in future speech and language test development. Such issues include the presence of conjugations and inflections in almost all of the Arabic words. For example, /ækælæt/ (she ate). These make item selection challenging, and given that this is no standard approach for dealing with these issues, this could introduce methodological bias and potentially, make comparison across different tests, difficult. Another aspect that should be considered in developing tests in Arabic is the wide range of different dialects. In the current study only one dialect was chosen (Najdi). It would be more practical to develop a test that contains words that are mutually intelligible in all dialects so that it can be used across the whole country without being confounded by familiarity issues. Clinical assessments often require that the test be repeated every 6 months at least in order to monitor progress over time. The ALNT has proven to be highly sensitive and reliable in assessing speech perception and learning effects were not apparent as long as the time period between tests was at least 6 months.

6.2 Effects of demographic factors on ALNT and CV scores

6.2.1 Age at implantation

The fact that the effect of age at implantation was significantly correlated with speech perception on the ALNT implies that the earlier the children are implanted, the better. Thus candidacy criteria should be adjusted towards making age at implantation of less than 3 years a priority so children can get the most out of their CIs.

6.2.2 Length of implant use

In contrast to age at implantation, duration of implant use had no significant effect on the ALNT performance. This suggests that experience with the implant is not related to improvement in speech perception. This is surprising because most children with cochlear implants need a period of rehabilitation post-implantation in order to develop neural connections in the brain for the heard speech signals in order to establish a meaning for those signals. There are two possible reasons for this insignificant effect of duration in the current study: first, the low number of children who were tested in each session. Second, because more than half of the children had 4 years or more experience with their CI, the effect of duration of use may have begun to diminish especially that most of the improvement after cochlear implantation happens during the first 2 years.

6.3 Effects of Lexical factors on ALNT scores

One aim of developing an ALNT test was to explore the effect of lexical properties (word frequency and neighbourhood density) on word recognition. According to the NAM, easy words are expected to receive higher scores than hard words because of the effects of lexical properties. However, one should bear in mind that alternative explanations also exist. For instance, easy words may be easier for non-lexical reasons, perhaps because they comprise sounds that are easier to identify and have high phonotactic probability (Kirk et al., 1995). That said, consistent with the predictions of the NAM, the overall results of the ALNT across all studies in the present research were similar in that children identified the easy words with higher accuracy than the hard words.

Future research should focus on determining the factors that make a word easier or harder to recognise, particularly with reference to Arabic, as finding out these factors will shed more light on how words are perceived and processed in the Arabic language. This information will assist in designing rehabilitation programs and listening strategies that will allow children to improve their listening skills especially for words that are considered difficult to recognize.

6.4 Examination of the effects of neighbourhood density on word recognition

The effect of neighbourhood density on word recognition was further examined using three different methods. The first method, which comprised an exploration of the errors made by the children and comparison of those errors which were considered neighbours to the target word with those that were not, revealed that the hard words had more neighbour errors than the easy words. This is not surprising since the easy and hard words were constructed in this way. Nevertheless, for the group of CI children the number of neighbour words was reduced when compared to NH children. Possible reasons for this difference may include limitations in signal processing and limited fine discrimination skills which prevented them from identifying multiple phonemes in the target word. Consequently, the identified word would not be a neighbour of the target word according to the definition of neighbour adopted in this study. Also, because of the limited discrimination abilities in these children, the phonemes that are easily confused will make words and some of their non-neighbours sound very similar to each other. Consequently, another explanation could be that the CI children are simply familiar with fewer words that are considered neighbours for the target words.

The second method included examination of the phonetic features of the target words and the children's response words to find out if certain features resulted in easier or harder identification of the test words. The results of this method however were inconclusive as there was no certain phonetic feature that actually stood out between the groups of NH and CI children. The third and final method consisted of calculating the phoneme recognition scores to see whether phonetic cues affected word recognition. The phonemic scores were equivalent for the easy and hard words for the NH children but not the CI children implying that CI children may have been using different processes from NH children in word identification.

6.5 Re-examination of the definition of neighbour

The current attempt to investigate whether Arabic speaking children perceive words in a way that is consistent with the assumptions of the Neighbourhood Activation Model was successful in that both normal hearing (NH) children and children using cochlear implants (CI) scored higher on the easy words compared to the hard words. However, the fact that neighbourhood density only accounted for a small proportion of the variance in NH children in the noise condition and the fact that in CI children the contribution of familiarity was higher than neighbourhood density raises the question as to whether the definition used for neighbour is actually suitable for Arabic. Some of the other languages that have investigated neighbourhood density have used different definitions for neighbourhood density in order to suit their language. For example, in Mandarin Chinese the universally known definition of neighbourhood density (i.e. difference by one phone) was used in addition to another definition that incorporated tones. Tonal neighbourhood density refers to the number of words that are formed by adding substituting or deleting one tone for words that have the same sequence of phonemes (Liu et al., 2011; Liu et al., 2013). In Japanese however, two additional definitions were included in addition to the original neighbourhood definition. One definition included prosodic differences while the other included auditory calculations. In the prosodic neighbourhood density calculation, two stages were included before determining neighbourhood density for a word. The first stage included determining all the words that differed by one phoneme from the target word (i.e. the same definition used in the NAM). The second stage included selecting only the words that had the same tonal pattern as the target word from the candidate words that appeared in the first stage (e.g. if the target word had a low- high- high accent pattern then words that had a high- low- low pattern will not be considered neighbours). The third definition of neighbour was based on calculating auditory similarity between words according to spectral information (Yoneyama, 2002). In general, all these attempts were made in order to find a definition that best suits each language. And based on this, different results were found for each of the Mandarin and the Japanese studies. The Japanese study examined the three definitions in a word naming task. Because there was a huge range of response times between participants, they were divided into two groups (fast listeners and slow listeners). A word frequency effect was only found in the slow group. The authors' explanation of this was that only the slow group accessed the lexicon while performing the task. Discrepancies were also found between the two groups for neighbourhood density effects. For the fast listeners, the neighbourhood effect was found (although very small) for the first and second neighbourhood definitions (segments and segments + tonal pattern) and it explained 0.051% and 0.018% for the first and second definitions respectively. However, no neighbourhood density effect was found for the auditory definition. Conversely, for the slow listeners, neighbourhood density effects were significant but also very small for both the segment + tonal pattern and the auditory definition and it accounted for 0.036% and 0.054% of the variance for these two definitions respectively. Furthermore, unlike in the English, Chinese, and the current Arabic study, neighbourhood density was found to be facilitative instead of inhibitory with high density leading to higher naming performance. With regards to the Chinese studies (Liu et al., 2011; Liu et al., 2013; Wang et al., 2010; Yuen et al., 2008), even though they considered the tonal factor in the definition of neighbourhood density, their results were inconsistent. Wang et al. (2010) and Yuen et al. (2008) found a significant effect for the lexical factors of word frequency and neighbourhood density only in disyllables but not monosyllables whereas Liu et al. (2011) and Liu et al. (2013) found lexical effects in both monosyllables and disyllables.

The above mentioned studies have all made attempts to adjust the definition of the one phoneme difference rule in a way that would best suit each language. In English, attempts have also been made to discover whether the one phoneme difference rule was sufficient to define a neighbour. For example, a study by Bashford Jr, Warren, and Lenz (2006) used a technique called verbal transformation to evoke lexical neighbours. In this technique a single word is presented repeatedly with no gaps and participants are asked to report the words that they hear. For example the word “ace” when produced repeatedly with no gaps in between could elicit the word “say”. The findings of this study lead the authors to conclude that using only a one phoneme difference to define a neighbour may be too restrictive to cover all confusable words especially since words which had high neighbourhood density and low neighbourhood frequency (i.e. the sum of word frequencies of the lexical neighbours) elicited many words that differed by an average of 2 phonemes. Moreover, Vitevitch (2007) examined a modified definition of neighbourhood density which included the spread of neighbours within a lexical neighbourhood (i.e. calculating the number of phoneme position differences). For example, the word mop has the following neighbours hop, map, and mock and the number of positions in which a change can occur is 3 (initial, medial, and final). Therefore the spread is equal to 3. On the other hand if another word is considered (e.g. mob) change can occur in only two positions to form a meaningful word (i.e. initial and final) and the spread is therefore equal to 2. Vitevitch (2007) examined the concept of spread of neighbours in three tasks: auditory lexical decision task, naming task, and same-different task. Their findings demonstrated that words with a larger spread were responded to much slower than words with a smaller spread of neighbours indicating that the distribution of neighbours within a neighbourhood does affect word recognition.

Given all this, it is essential to conduct such experiments in Arabic in order to discover what really constitutes a neighbour in Arabic. Furthermore, given that phonotactic probability and lexical neighbourhood density are tied up with one another, it is essential to investigate these factors separately to gain more understanding about the factors that contribute to lexical access.

6.6 Shortcomings of the single phoneme difference definition of neighbour

Because the single phoneme difference definition is binary, it fails to take account of several aspects such as the position at which the single phoneme is different, that is whether it is in initial, medial, or final position. It also does not take into account the difference in phonological features of the changed phonemes (e.g. the words that differ in manner and voicing (e.g. mat and cat) are given the same weight as those that differ by voicing only (e.g. bat and pat). Additionally it fails to take into the germination process and this is important especially in Arabic words (e.g. /ʃæʈ̈ʈæh/). According to the original definition of neighbour, the word (/ʃæʈ̈ʈæh/= hot sauce) can have the following neighbours (/ʃænʈæh/, /bæʈ̈ʈæh/, /ʃæʈ̈ʈæf/, /ʃæχʈæh/, and /næʈ̈ʈæh/) but the following word cannot be considered a neighbour (/ʃæɗ̈dæh/) because two phonemes have been changed. Therefore it is imperative to find out what constitutes the basis of lexical competition in the Arabic language in order to further investigate if lexical neighbours do indeed affect recognition at the word level.

6.7 Eliciting neighbours in Arabic speaking children for future experiments

Further experiments may be necessary to assist in evoking confusable words in children especially that both CI and NH children did produce words that were considered neighbours of the target word during testing. The fact that this occurred demonstrates that the neighbourhood density count used was not accurate. It would be expected that neighbourhood density would be proportionate to sample size but it could also be the case that the use of different materials for language sampling may have led to the elicitation of different word neighbours. Therefore, different experiments that aim at eliciting confusable words will not only allow a more accurate count of neighbourhood density but will also aid in revising the definition of what makes a word confusable. Although it is reasonable to think that neighbourhood density should be proportionate to the size of the language sample, it is possible that results may have been different if the number of neighbours was not restricted to those present in the language samples collected. This is supported by the new word neighbours that were generated by both CI and NH children during testing sessions that were not included in the language samples and consequently not included in the neighbourhood count. However, unlike in adults where neighbourhood density can be extracted from larger sources such as dictionaries, it would be difficult to gauge the size of neighbourhood density in children especially that their language skills are still developing. One way of doing this is to conduct experiments that allow children to generate neighbours of the target words and include them in the neighbourhood density count. Given the statement above about the proportion of neighbourhood density to language size, it would be reasonable to include the same children in both language sampling and in experiments for generating neighbours in order to be able to further examine this assumption.

6.8 Conclusion

Overall, the results of the experiments that were conducted in the current research were all consistent with the concept of the Neighbourhood Activation Model. However, the inconsistent results regarding the contribution of neighbourhood density in word recognition across the three groups of children (i.e. NH children in noise and in vocoded speech conditions and children using CIs) raises the question as to whether the definition used in English is actually suitable for Arabic language. In other words, it may not be appropriate to use the outcomes of the ALNT to make assumptions about how children organize words in their mental lexicon as it might be the case that Arabic requires a more complex model to explain the organization of words in the mental lexicon and their retrieval. This implies that the current definition of NAM may need to be revised in order to accommodate Arabic and that caution should be taken when applying theories of speech perception across languages especially as they may not have the same effect in one language compared to another language. In conclusion, the Arabic Lexical Neighbourhood Test can be used as a reliable and sensitive speech perception measure in children using cochlear implants for the purpose of clinical assessment only but care should be taken in generalizing the theoretical assumptions of NAM to lexical processing in Arabic-speaking children.

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8 Appendix

8.1 Hearing Screening form

Child's Name: ____

Date: ___/___/2011

DOB: ______/______/_______ **Age:** _______

Pure Tone:

Screen: Pass ☐ Fail ☐

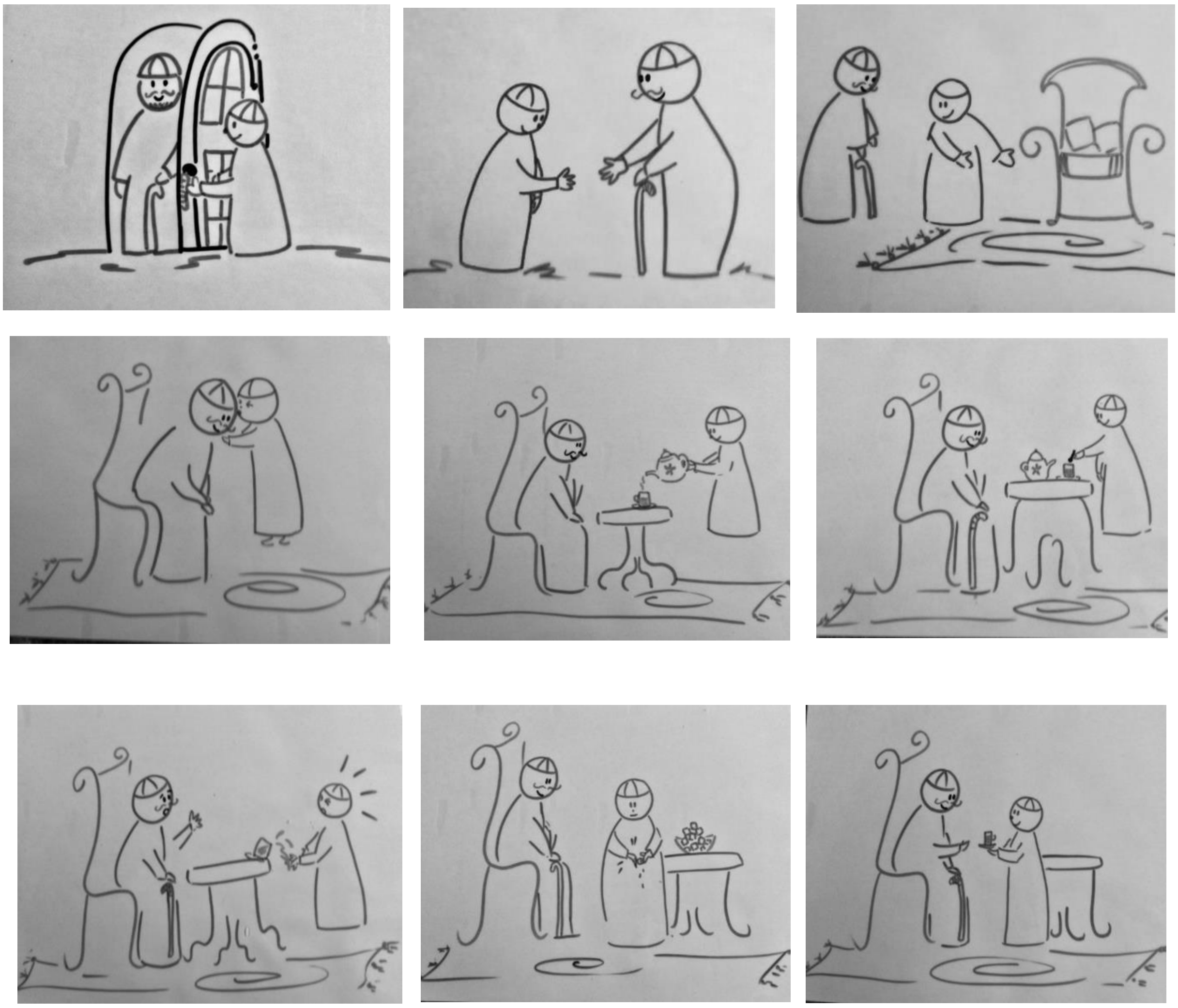
	Right Ear					Left Ear			
Level (dB)	25	20	20	20		25	20	20	20
Frequency (Hz)	500	1000	2000	4000		500	1000	2000	4000

Reliability: Good ☐ Fair ☐ Poor ☐

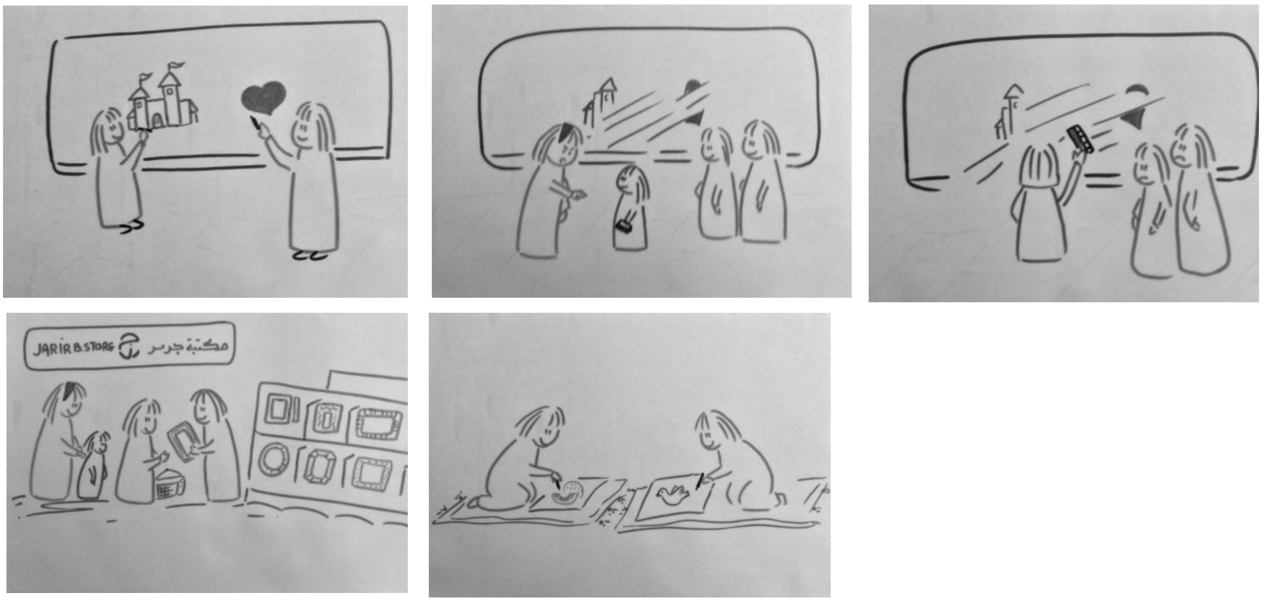
Nada A. Alsari

8.2 Story retelling pictures

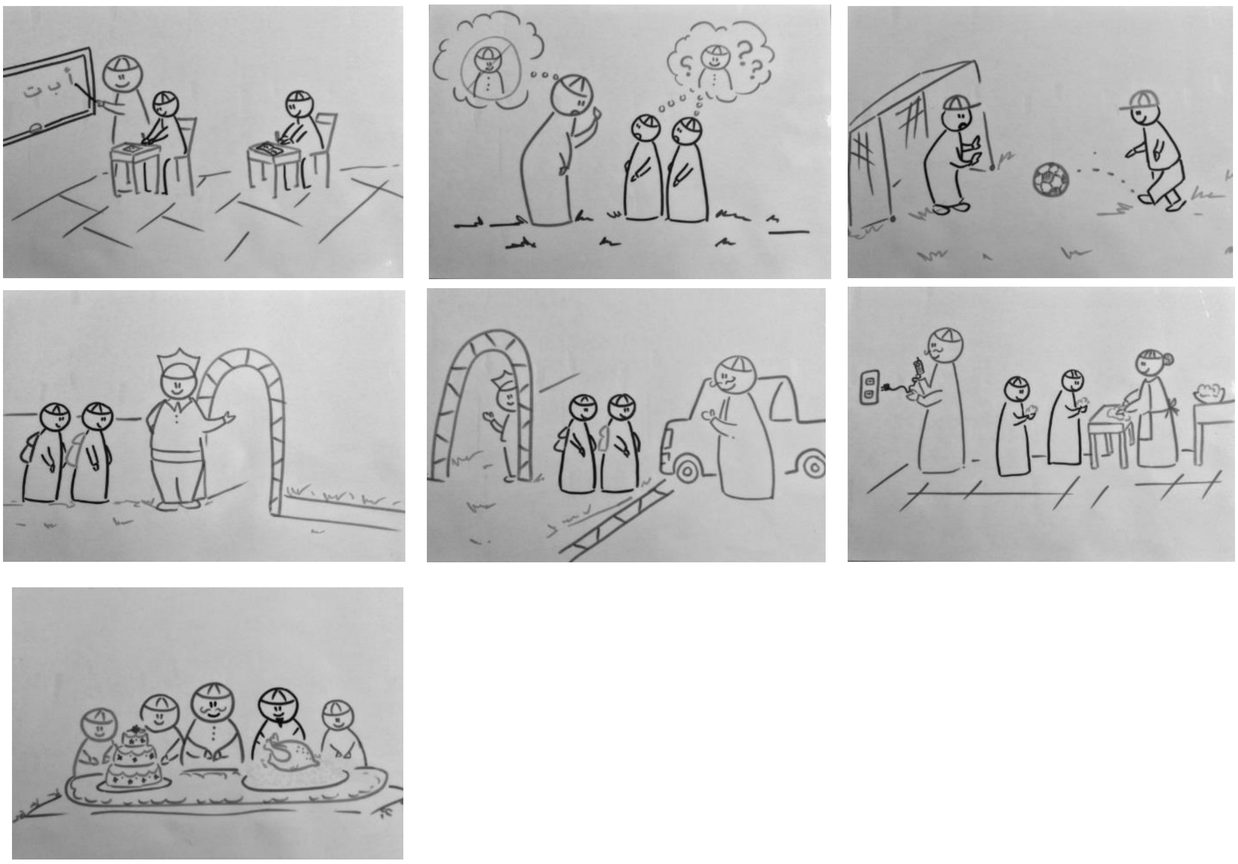
8.2.1 Story1 for language sampling



8.2.2 Story2 for language sampling



8.2.3 Story 3 for language sampling



8.3 Easy and Hard words with Neighbourhood density and word frequency counts

8.3.1 Easy words with neighbourhood density and word frequency counts

Easy words	Neighbour-hood density	Word frequency	Easy words	Neighbour-hood density	Word frequency
1. /bæʕdeːn/	0	779	26. /læħæm/	0	27
2. /ħælib/	0	160	27. /ʂæʕəb/	0	23
3. /ʃæːhi/	0	146	28. /zæʕlæːn/	0	22
4. /ræsæm/	0	98	29. /θæːnjæ/	0	22
5. /seːkæl/	0	78	30. /ɪʒlɪs/	0	20
6. /χæruf/	0	63	31. /ʈɑwlæh/	0	20
7. /ʃokæ/	0	60	32. /dʊmjæ/	0	18
8. /ʒæzmæ/	0	59	33. /ʂællɪħ/	0	18
9. /tæʕbæːn/	0	58	34. /sɪʒɪn/	0	18
10. /læjmun/	0	56	35. /sæʒʒæl/	0	17
11. /ɣæssɪl/	0	53	36. /fuʈæh/	0	16
12. /dæbbæːb/	0	49	37. /mæssəħ/	0	16
13. /ʒæzær/	0	49	38. /næʐʐəf/	0	16
14. /æbjæʐ/	0	46	39. /χælæːʂ/	0	15
15. /ɣɑjɪb/	0	42	40. /dudæ/	0	14
16. /tæħæt/	0	42	41. /zæjjɪn/	0	14
17. /ʕæʒin/	0	40	42. /jæʕni/	0	13
18. /ʒæwwɑl/	0	39	43. /qæfæʂ/	0	13
19. /sɪkkin/	0	37	44. /mæʃʃɪʈ/	0	12
20. /ɪnkʌb/	0	36	45. /ʈæwil/	0	12
21. /ɪʃħæn/	0	33	46. /læwwɪn/	0	11
22. /hædæf/	0	30	47. /bʌʈʈiχ/	0	10
23. /ʕæʂfur/	0	30	48. /dæræʒ/	0	10
24. /θæːni/	0	30	49. /ħæʂʂæl/	0	10
25. /χærbɑn/	0	29	50. /mækæːn/	0	10

8.3.2 Hard words with neighbourhood density and word frequency counts

Hard words	Neighbour-hood density	Word frequency	Hard words	Neighbour-hood density	Word frequency
1. /ækəl/	2	1	26. /sæʕid/	2	2
2. /ælæm/	2	1	27. /ʕæbbæ/	2	2
3. /æqæl/	2	1	28. /χælæʈ/	2	2
4. /bæʕid/	2	1	29. /ħælwæ/	2	3
5. /ɖæræb/	2	1	30. /ɪʈɑr/	2	3
6. /færæs/	2	1	31. /χæːlæ/	2	3
7. /ɪrfæʕ/	2	1	32. /æbæd/	3	1
8. /kæsær/	2	1	33. /færæħ/	3	1
9. /næːdæ/	2	1	34. /ʂællæ/	3	1
10. /næːdi/	2	1	35. /ʒæmæʕ/	3	1
11. /næmɪl/	2	1	36. /gælæb/	3	2
12. /qæwi/	2	1	37. /ħælæg/	3	2
13. /ræmɪl/	2	1	38. /kæfær/	3	3
14. /sæːħæ/	2	1	39. /ʕællæm/	3	3
15. /sæbʕæ/	2	1	40. /mæʃæ/	4	1
16. /ʂædər/	2	1	41. /sæmæħ/	4	3
17. /sæʒæd/	2	1	42. /χællæ/	5	3
18. /ʒærrɪb/	2	1	43. /wæræ/	7	3
19. /ʕællæg/	2	1	44. /ʃæræb/	4	4
20. /χæbbæ/	2	1	45. /færrɪʃ/	3	4
21. /χæʈær/	2	1	46. /kællæm/	2	4
22. /ʃæʈʈæ/	2	2	47. /wæʂæl/	2	4
23. /ɣæræg/	2	2	48. /ʕæːdi/	2	4
24. /ræmæ/	2	2	49. /tæræ/	4	3
25. /sæːʕæd/	2	2	50. /sæmæ/	6	3

8.4 Between words Stimuli (used for training purposes and for the adaptive SNR test)

1. æχæð	26. mætin
2. bæːrɪd	27. mæʈʕæm
3. bʌrræh	28. mæʕʒun
4. dæftær	29. məndil
5. dɑχɪl	30. mɪskin
6. ʃɑʈər	31. næːʒəħ
7. ʃʌnʈæ	32. næʃʃæf
8. færħɑn	33. næʒmæ
9. ɣænæm	34. ræʂif
10. ɣæzæːl	35. ʂægər
11. ræwʐæ	36. ɖəfdæʕ
12. gɪddæːm	37. ʂɑruχ
13. ħæːrɪs	38. ʂʌfħæ
14. ħæbəl	39. ʂʌndæl
15. ħæflæh	40. ʈæbib
16. ħæʒəm	41. ʈæħin
17. hɪlæːl	42. wærdæh
18. ɪbni	43. wɑʒɪb
19. ɪsʕæːf	44. ʕæʂʂæb
20. ɪθneːn	45. ʕæzæm
21. mæːʕɪz	46. fæːjɪz
22. mæftuħ	47. ʕɪlbæ
23. mælɪk	48. θæʕlæb
24. mæsʒɪd	49. χæmsæ
25. mæʈbæχ	50. χeːmæ

8.5 Easy and Hard words divided in to two equally difficult lists

8.5.1 Easy list 1

Phonetic	Arabic	Meaning
ʂæʕəb	صعب	difficult
ræsæm	رسم	drew
ħæʂʂæl	حصَل	found
ɪʃħæn	إشحن	charge (verb)
sæʒʒæl	سجَل	recorded
næʐʐəf	نظِف	clean (verb)
ʒæzmæ	جزمة	shoe
dæbbæ ː b	دبَاب	motorbike
qæfæʂ	قفص	cage
dʊmjæ	دُمية	doll
ħælib	حليب	milk
θæ ː ni	ثاني	second
ɪʒlɪs	إجلس	sit
læwwɪn	لوِن	colour(verb)
mæssəħ	مسِح	wipe
bæʕde ː n	بعدين	then/after that
dudæ	دودة	worm
χærbɑn	خربان	damaged
ʃæ ː hi	شاهي	tea
χælæ ː ʂ	خلاص	finish
tæħæt	تحت	down/under
bʌʈʈiχ	بطيخ	watermelon
ʒæzær	جزر	carrot
fuʈæh	فوطه	towel
se ː kæl	سيكل	bicycle

8.5.2 Easy list 2

Phonetic	Arabic	Meaning
ɣɑjɪb	غايب	absent
θæ ː njæ	ثانية	another
ʂællɪħ	صلِح	fix
ɣæssɪl	غسِل	wash
læħæm	لحم	meat
æbjæʐ	أبيض	white
zæjjɪn	زين	tidy (verb)
ɪnkʌb	انكب	spilt
mæʃʃɪʈ	مشِط	comb (verb)
tæʕbæ ː n	تعبان	sick
ʈɑwlæh	طاولة	table
dæræʒ	درج	stairs
ʈæwil	طويل	tall/long
ʃokæ	شوكة	fork
læjmun	ليمون	lemon
jæʕni	يعني	means
χæruf	خروف	sheep
hædæf	هدف	goal
ʕæʒin	عجين	dough
ʕæʂfur	عصفور	bird
zæʕlæ ː n	زعلان	upset
mækæ ː n	مكان	place
sɪʒɪn	سِجن	jail
ʒæwwɑl	جوَال	mobile phone
sɪkkin	سكين	knife

8.5.3 Hard list 1

Phonetic	Arabic	Word meaning
sæ ː ʕæd	ساعَد	helped
χælæʈ	خلط	stirred
sæ ː ħæ	ساحة	hall
kællæm	كلَّم	spoke to/ talked to
ɪrfæʕ	إرفع	lift(verb)
tæræ	ترى	See/look
æqæl	أقل	less than
ɖæræb	ضَرَب	hit
ʂællæ	صَلَّى	prayed
wæræ	ورى	behind
ælæm	ألم	pain
sæmæ	سما	sky
ræmɪl	رمِل	sand
ʃæræb	شَرَب	drank
ʕæbbæ	عبَا	filled
ħælæɡ	حَلَق	shaved
χæbbæ	خبَا	hid something
ħælwæ	حلوى	sweets
ʂædər	صدر	chest
færrɪʃ	فرِش	brush (verb)
χællæ	خلَّى	left (verb)
næ ː dæ	نادى	called
χæʈær	خطر	danger
færæs	فرس	horse
næ ː di	نادي	club

8.5.4 Hard list 2

Phonetic	Arabic	Word meaning
sæmæħ	سَمَح	allowed
ræmæ	رمى	threw
ɪʈɑr	إطار	frame
gælæb	قَلَب	turned over
ʕællæg	عَلَق	hung
χæ ː læ	خالة	aunt
ʕællæm	علَم	taught
wæʂæl	وَصَل	arrived
qæwi	قوي	strong
sæʒæd	سَجَد	kneeled
ʒærrɪb	جرِب	try (verb)
mæʃæ	مَشى	walked
kæsær	كَسَر	broke
æbæd	أبَد	at all
ɣæræg	غَرَق	drowned
ʒæmæʕ	جَمَع	gathered
kæfær	كَفَر	tire (noun)
bæʕid	بعيد	far
næmɪl	نَمِل	ant
ʃæʈʈæ	شطَة	hot sauce
færæħ	فَرَح	became joyful
ʕæ ː di	عادي	normal
sæʕid	سعيد	happy
ækəl	أكِل	food
sæbʕæ	سبعة	seven

8.6 Test-Retest Study design

- Testing was be conducted over two sessions
- Each of the hard and easy lists is divided into 3 lists (a, b, and c).
- For each child, one list was presented only in the first session, one list was presented in the second session only, and one list was repeated in both the first and second sessions.
- The remaining two words from each of the hard and the easy lists were presented in both sessions.
- The design was conducted in blocks of 6 as follows:

	First session	**Second session**
Subject 1	easy/hard (a) + (b) + 2 easy+2 hard words	easy/hard (a) + (c) + 2 easy+2 hard words
Subject 2	easy/hard (a) + (b) + 2 easy+2 hard words	easy/hard (b) + (c) + 2 easy+2 hard words
Subject 3	easy/hard (a) + (c) + 2 easy+2 hard words	easy/hard (b) + (c) + 2 easy+2 hard words
Subject 4	easy/hard (a) + (c) + 2 easy+2 hard words	easy/hard (a) + (b) + 2 easy+2 hard words
Subject 5	easy/hard (b) + (c) + 2 easy+2 hard words	easy/hard (a) + (b) + 2 easy+2 hard words
Subject 6	easy/hard (b) + (c) + 2 easy+2 hard words	easy/hard (a) + (c) + 2 easy+2 hard words

8.7 CI children study design

- Testing were conducted over three sessions
- Each of the hard and easy lists is divided into 4 lists (i, j, k, and l).
- For each child, one list were presented only in the first session, one list was presented in the second session only, one list was presented in the third session only and one list was repeated in all three sessions.
- The remaining two words from each of the hard and the easy lists were presented in all three sessions.
- The design was be conducted in blocks of 8 as follows:

	First session	**Second session**	**Third session**
Subject 1	easy/hard (i) + (j) + 2 easy+2 hard words	easy/hard (i) + (k) + 2 easy+2 hard words	easy/hard (i) + (l) + 2 easy+2 hard words
Subject 2	easy/hard (i) + (j) + 2 easy+2 hard words	easy/hard (j) + (k) + 2 easy+2 hard words	easy/hard (j) + (l) + 2 easy+2 hard words
Subject 3	easy/hard (i) + (k) + 2 easy+2 hard words	easy/hard (j) + (k) + 2 easy+2 hard words	easy/hard (k) + (l) + 2 easy+2 hard words
Subject 4	easy/hard (i) + (l) + 2 easy+2 hard words	easy/hard (j) + (l) + 2 easy+2 hard words	easy/hard (k) + (l) + 2 easy+2 hard words
Subject 5	easy/hard (i) + (l) + 2 easy+2 hard words	easy/hard (i) + (k) + 2 easy+2 hard words	easy/hard (i) + (j) + 2 easy+2 hard words
Subject 6	easy/hard (j) + (l) + 2 easy+2 hard words	easy/hard (j) + (k) + 2 easy+2 hard words	easy/hard (i) + (j) + 2 easy+2 hard words
Subject 7	easy/hard (k) + (l) + 2 easy+2 hard words	easy/hard (j) + (k) + 2 easy+2 hard words	easy/hard (i) + (k) + 2 easy+2 hard words
Subject 8	easy/hard (k) + (l) + 2 easy+2 hard words	easy/hard (j) + (l) + 2 easy+2 hard words	easy/hard (i) + (l) + 2 easy+2 hard words

8.8 Nonsense syllables (CVs) for CI children only

CVs /a/ context	CVs /i/ context
1. /ba/	1. /bi/
2. /da/	2. /di/
3. /ga/	3. /gi/
4. /ħa/	4. /ħi/
5. /ja/	5. /ji/
6. /ka/	6. /ki/
7. /ma/	7. /mi/
8. /ra/	8. /ri/
9. /sa/	9. /si/
10. /ʃa/	10. /ʃi/
11. /ta/	11. /ti/
12. /wa/	12. /wi/
13. /χa/	13. /χi/
14. /za/	14. /zi/
15. /ʕa/	15. /ʕi/
16. /ɣa/	16. /ɣi/

8.9 Patient information form

Patient information	
Name:	**File#:**
Date of testing	
Age at testing	
Date of birth	
Date of cochlear implantation	
Age at implantation	
Etiology of hearing loss	
Age of onset of hearing loss	
Communication mode	
Cochlear implant brand	
Type of processor	
Type of strategy	
Number of active electrodes	
Unaided pure tone audiogram	Attach

8.10 Familiarity rating form

Please rate your child's familiarity with the following words.
Name:

أرجو تحديد مدى معرفة الطفل بالكلمات التالية. شكرا لتعاونكم.
الإسم:

Child's familiarity rating		معرفة الطفل بها	Word	الكلمة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʂæʕəb/	صعب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ræsæm/	رَسَم
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ħæʂʂæl/	حصَّل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɪʃħæn/	إشحن
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæʒʒæl/	سَجَّل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/næʐʐəf/	نظِّف
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʒæzmæ/	جزمة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/dæbbæ : b/	دبَّاب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/qæfæʂ/	قفص
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/dʊmjæ/	دُمية
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ħælib/	حليب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/θæ : ni/	ثاني
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɪʒlɪs/	إجلس
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/læwwɪn/	لوِن
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/mæssəħ/	مَسِّح
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/bæʕde : n/	بعدين
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/dudæ/	دودة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χærbɑn/	خربان
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʃæ : hi/	شاهي
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χælæ : ʂ/	خلاص
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/tæħæt/	تحت
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/bʌʈʈiχ/	بطيخ
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʒæzær/	جَزَر
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/fuʈæh/	فوطة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/se : kæl/	سيكل

Please rate your child's familiarity with the following words.
Name:

أرجو تحديد مدى معرفة الطفل بالكلمات التالية. شكرا لتعاونكم.
الإسم:

Child's familiarity rating		معرفة الطفل بها	Word	الكلمة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɣɑjɪb/	غايب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/θæ ː njæ/	ثانية
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʂællɪħ/	صَلِّح
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɣæssɪl/	غَسِّل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/Læħæm/	لحم
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/æbjæʐ/	أبيض
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/zæjjɪn/	زيِّن
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɪnkʌb/	إنكب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/mæʃʃɪƫ/	مَشِّط
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/tæʕbæ ː n/	تعبان
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ƫɑwlæh/	طاولة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/dæræʒ/	دَرَج
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ƫæwil/	طويل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʃokæ/	شوكة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/læjmun/	ليمون
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/jæʕni/	يعني
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χæruf/	خروف
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/Hædæf/	هدف
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʕæʒin/	عجين
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʕæʂfur/	عصفور
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/zæʕlæ ː n/	زعلان
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/mækæ ː n/	مكان
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sɪʒɪn/	سِجِن
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʒæwwɑl/	جوّال
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sɪkkin/	سكين

Please rate your child's familiarity with the following words.
Name:

أرجو تحديد مدى معرفة الطفل بالكلمات التالية. شكرا لتعاونكم.
الإسم:

Child's familiarity rating		معرفة الطفل بها	Word	الكلمة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæ ː ʕæd/	ساعَد
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χælæʈ/	خلط
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæ ː ħæ/	ساحة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/Kællæm/	كلَّم
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɪrfæʕ/	إرفع
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/tæræ/	ترى
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/æqæl/	أقل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɖæræb/	ضَرَب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʂællæ/	صلَّح
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/wæræ/	ورى
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ælæm/	ألم
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæmæ/	سَما/سماء
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ræmɪl/	رمل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʃæræb/	شَرَب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʕæbbæ/	عبَّى/عبأ
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ħælæg/	حَلَق
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χæbbæ/	خبَّى/ خبأ
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ħælwæ/	حلوى
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʂædər/	صدر
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/færrɪʃ/	فرِّش
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χællæ/	خلّا
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/næ ː dæ/	نادى
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χæʈær/	خطر
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/færæs/	فرس
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/næ ː di/	نادي

Please rate your child's familiarity with the following words.
Name:

أرجو تحديد مدى معرفة الطفل بالكلمات التالية. شكرا لتعاونكم.
الإسم:

Child's familiarity rating		**معرفة الطفل بها**	**Word**	**الكلمة**
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæmæħ/	سَمَح
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ræmæ/	رمى
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɪʈɑr/	إطار
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/gælæb/	قَلَب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʕællæg/	علَّق
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/χæ ː læ/	خالة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʕællæm/	علَّم
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/wæʂæl/	وَصَل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/qæwi/	قوي
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæʒæd/	سجد
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʒærrɪb/	جرِّب
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/mæʃæ/	مشى
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/kæsær/	كَسَر
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/æbæd/	أبد
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ɣæræg/	غَرَق
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʒæmæʕ/	جَمَع
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/kæfær/	كفر
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/bæʕid/	بعيد
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/næmɪl/	نمل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʃæʈʈæ/	شطِّة
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/færæħ/	فرح
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ʕæ ː di/	عادي
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæʕid/	سعيد
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/ækəl/	أكِل
I don't know/لا أعرف ☐	No/لا ☐	Yes/نعم ☐	/sæbʕæ/	سبعة

8.11 Confusion matrices for SINFA and first iteration results

8.11.1 Easy consonants first position (NH in noise)

	Perceived Sounds																												
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	40					1	1						1							1								1	
	d	5	63			2	3					3		2						1	2	2				1			1	1
	ɖ																													
	ð																													
	f					24																								
	g																													
	ɣ	4		1		1		14		2			2	1		5	6					2			1			3		2
	h								18																			1		
	ħ								1	36						2										1		3		
	j						1				16	1		1	1											1		1		
	k																													
	l	7	1				1				1	1	40	1	12						2			2		1		1		
	m	1												60	4					1			1							
	n													3	10	3			1			1						1		4
	q	1				1	1						1			19						1								
	r	7								1				1		2	6						3					3		
	s													4				91					1							
	ʂ															2		4	40											
	ʃ	1																		46										
	t		1									2						2	2	1	33								4	
	ʈ					1		2								12				1	1	28								1
	w																													
	z	2					1											1						42					1	
	ʐ																													
	ʒ		1			1						3														66				
	ʔ																													
	ʕ	1												4	2		1											39		
	θ		5						1	1				1	1	1					7								24	1
	χ	3				3				1							2					2								56

8.11.2 Easy consonants second position (NH in noise)

		Perceived Sounds																											
		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
Stimulus Sounds	b	32	3			2									1		3									2		1		
	d	1	39		2								3		1								1							
	ɖ																													
	ð																													
	f					22													2											
	g																													
	ɣ																													
	h					1			18	1							1											2		
	ħ								1	46																				
	j						1		1		52		9		3		4													
	k						2					86										5								
	l		8								1		38	3	10	1	6					1	1						1	
	m		2											15	4								2							
	n	3	1			1	1		1			2	3	3	49			1	1		1	1						1		
	q																													
	r	5						1							1		53		1			1	1		2		1			
	s													1				46	19	1				2						
	ʂ												1					5	41											
	ʃ									2				2			1	2		39										
	t																													
	ʈ																2					46								
	w	1	1			1							2	4	1		1					2	80							
	z																	1	1					45						
	ʐ	3				4							1	2			1					1			11					
	ʒ	1					1						1		1		1	4								87				
	ʔ																													
	ʕ	13	3			2				11	1		1	1	1	3	2	1	1								1	74		
	θ																													
	χ																													

8.11.3 Easy consonants third position (NH in noise)

		Perceived Sounds																												
		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
Stimulus Sounds	B	54	4			3											1				1	1			1		1			
	D	2	17												1		1													
	ɖ																													
	Đ																													
	F					19	1			1																				2
	g																													
	ɣ																													
	H																													
	Ħ								1	7							1											5		
	J		3								36		7	5	8							1							1	
	K	1					1					36					2													1
	L	1	7						1				54		3		5									2				
	m										2			26	6															
	n		1											1	17			1												
	q																													
	r																													
	s												1	1				27	2	1						1				
	ʂ														2			1	17											
	ʃ								3											11		3				1				
	t																													
	ʈ																				1	23								
	w	1												1	2		1						40							
	z																													
	ʐ	3				2							1	1	1			1						1	10					
	ʒ																									17				
	ʔ																													
	ʕ																													
	θ																													
	χ																													

8.11.4 Easy consonants fourth position (NH in noise)

Stimulus Sounds	Perceived Sounds																												
	b	d	ḍ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	42	2			1	2	1		2	1	2	2	4	12		9						1			1				
d																													
ḍ																													
ð																													
f					52	1						1				3	1	1					4	1					
g																													
ɣ																													
h	2							36				1				1	1					1	1						
ħ		1				2			22		1	4				5										1			
j																													
k																													
l	1	2			2			2	2	3		85	8	5	1	6					2		1		4				
m					1	1						12	13			5				1	1								
n	5	1			1			4	1		3	6	5	222		5				1							1		
q																													
r	2					1						1	2			42													
s	7											2		1			12						2						
ʂ												1					4	30	1		1		9						
ʃ																													
t	1																			18									
ʈ		5														1					12								
w																													
z																													
ʐ	2		1											1										7					
ʒ	3																								12				
ʔ																													
ʕ																													
θ																													
χ															1														23

8.11.5 Easy vowels first position (NH in noise)

		Perceived Sounds												
Stimulus Sounds		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
	æ	688	5	2		2	30	3	26	2	1	2	24	1
	æː	1	64			1			2				1	
	ɑ	3	4	33			1		1	2			1	
	e													
	eː					24								
	ə													
	i													
	ɪ	17	1			1	1		95				3	1
	o		1	3			1			18		1		
	ɔ													
	u								1			43	3	
	ʊ	2					1	1	1			2	17	
	ʌ						6						2	16

8.11.6 Easy vowels second position (NH in noise)

		Perceived Sounds												
Stimulus Sounds		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
	æ	337	1	9			25	20	20			2	1	
	æː	2	105	6					1					
	ɑ		4	43										
	e													
	eː	1	1	1		19		2						
	ə	8	1	1			34	4	5					
	i	10		1		1	1	166	3			2	1	
	ɪ	26	1	1			17	20	100			1		
	o													
	ɔ													
	u		1					2	1		1	64		
	ʊ													
	ʌ	6	1	1							1			13

8.11.7 Hard consonants first position (NH in noise)

		Perceived Sounds																											
		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
Stimulus Sounds	b	22				1																			1					
	d																													
	ɖ	7	1	8				1														2	2		2					
	ð																													
	f					71																				1				
	g						19									2	1									1				
	ɣ	1				2		12		1							1						5					1		1
	h																													
	ħ								1	45																				2
	j																													
	k	1				2	1			5		39				14	1				1	1						2		1
	l																													
	m													21																
	n	1	1						3				1		65			1												
	q													1		15									1					1
	r	1				2		1						1		15	12								2			12		
	s		1											1				153	8	2										
	ʂ																	2	46											
	ʃ																	2		46										
	t						1					4	1		1		1				11	2								
	ʈ																													
	w	3				1		1						3	1	2							35							1
	z																													
	ʐ																													
	ʒ																			1	1					45				1
	ʔ																													
	ʕ									2	1			5														68		
	θ																													

		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	χ	2				3		6		6				1		4			2			2						2		83

8.11.8 Hard consonants second position (NH in noise)

		Perceived Sounds																												
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	73	2	2									1	6			3					3			3					
	d		82		2		1				2		1		3							2				2				
	ɖ																													
	ð																													
	f	1				20													3											
	g																													
	ɣ																													
	h																													
	ħ					1				11							1	1										9		
	j																													
	k											23									1									
	l	6	9			1			1	3	6		163	12	18		25				1	2	1			1	2	2		
	m	3												136	1							1			1					
	n																													
	q		1								1		10			7					1	1								1
	r	5	7		1	6			1	1		1	5		1	1	184	3			1	4		2		1	3	4		
	s					1												14	8											
	ʂ					1												3	20											
	ʃ																			21										
	t																													
	ʈ	1	1													3	1					64			1					
	w													1	1								18	1						
	z																													
	ʐ																													
	ʒ		3																							21				
	ʔ																													
	ʕ		3			1		3	1						1		3										2	57		

	θ																													
	χ																													

8.11.9 Hard consonants third position (NH in noise)

		Perceived Sounds																												
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	29	3	1				2						1			2					3			3					
	d																													
	ɖ																													
	ð																													
	f	1				16											1				1									
	g																													
	ɣ																													
	h																													
	ħ																													
	j																													
	k																													
	l	1	9				1				2		49	5	23		1													
	m																													
	n																													
	q																													
	r		4							1		1	1		1		25			2										
	s																													
	ʂ																													
	ʃ																													
	t																													
	ʈ											1										19								
	w	1	1												1								19							
	z																													
	ʐ																													
	ʒ																													
	ʔ																													

ʕ																										22		
θ																												
χ																												

8.11.10 Hard consonants fourth position (NH in noise)

	Perceived Sounds																												
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	30	2			6	3	1				1	2	15	2	2	8					1				1		1		
	d		55	1		1	1		3		1		12	1	12		9	1												
	ɖ																													
	ð																													
	f																													
	g	13	4			2	30			1			3	6	1	4						2								
	ɣ																													
	h																													
	ħ							1		18		7				2	3	1										1		
	j																													
	k																													
	l	1	3						1			1	57	1	2		13		1		1	9								
	m	9				2			1				4	33	1		1													
	n																													
	q																													
	r	3				1	2						6	2	2	2	85		5								4			
	s																	22												
	ʂ																													
	ʃ																1			21										
	t																													
	ʈ	2				2								2			3		4			5			1					
	w																													
	z																													
	ʐ																													
	ʒ																													

	ʔ																													
	ʕ							1					8			1	2											15		
	θ																													
	χ																													

8.11.11 Hard vowels first position (NH in noise)

		Perceived Sounds												
Stimulus Sounds		æ	æ:	ɑ	e	e:	ə	i	ı	o	ɔ	u	ʊ	ʌ
	æ	900	11	9		1	13		22	4		1	17	3
	æ:	2	118	16					2					
	ɑ													
	e													
	e:													
	ə													
	i													
	ı	9					2		30				3	
	o													
	ɔ													
	u													
	ʊ													
	ʌ													

8.11.12 Hard vowels second position (NH in noise)

		Perceived Sounds												
		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
Stimulus Sounds	æ	727	10	6		1	32	9	40			2	3	
	æː													
	ɑ	1		22										
	e													
	eː													
	ə	3				1	33	3	6					
	i	10					3	94	25					
	ɪ	21					7	1	35			1		
	o													
	ɔ													
	u													
	ʊ													
	ʌ	727	10	6		1	32	9	40			2	3	

8.11.13 Easy consonants first position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.999	0.619	0.62	0.191	0.925
Place	2.933	1.976	0.674	0.608	0.812
Manner	1.61	0.856	0.532	0.263	0.85
Duration	0.874	0.679	0.777	0.209	0.969

8.11.14 Easy consonants second position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.927	0.648	0.699	0.205	0.945
Place	3.097	2.189	0.707	0.691	0.828
Manner	1.773	1.146	0.646	0.361	0.884
Duration	0.831	0.702	0.845	0.222	0.982

8.11.15 Easy consonants third position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.911	0.6	0.658	0.204	0.943
Place	3.04	2.093	0.688	0.712	0.808
Manner	1.893	1.259	0.665	0.429	0.877
Duration	0.649	0.467	0.72	0.159	0.972

8.11.16 Easy consonants fourth position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.91	0.442	0.486	0.198	0.9
Place	2.119	1.175	0.554	0.525	0.789
Manner	1.92	0.98	0.51	0.438	0.807
Duration	0.472	0.281	0.595	0.126	0.966

8.11.17 Easy vowels first position first iteration (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.672	0.404	0.601	0.323	0.925
Height	0.88	0.461	0.524	0.369	0.883
Duration	0.68	0.499	0.734	0.399	0.969

8.11.18 Easy vowels second position first iteration (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.836	0.442	0.528	0.27	0.905
Height	1.276	0.622	0.487	0.38	0.859
Duration	0.971	0.605	0.623	0.37	0.923

8.11.19 Hard consonants first position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.973	0.63	0.648	0.2	0.936
Place	2.898	2.071	0.715	0.659	0.838
Manner	1.491	0.899	0.603	0.286	0.896
Duration	0.891	0.819	0.919	0.26	0.991

8.11.20 Hard consonants first position second iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.721	0.432	0.6	0.173	0.941
Place	2.498	1.768	0.708	0.709	0.854
Manner	1.846	1.175	0.637	0.471	0.863
Duration	0.399	0.309	0.775	0.124	0.984

8.11.21 Hard consonants third position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.62	0.446	0.719	0.21	0.964
Place	2.122	1.646	0.776	0.776	0.814
Manner	1.38	0.828	0.601	0.391	0.755
Duration	0	0	0	0	0.992

8.11.22 Hard consonants fourth position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.626	0.264	0.423	0.147	0.891
Place	2.421	1.179	0.487	0.656	0.692
Manner	1.786	0.62	0.347	0.345	0.702
Duration	0.372	0.284	0.762	0.158	0.977

8.11.23 Hard vowels first position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0	0	0	0	0.942
Height	0.232	0.096	0.413	0.181	0.939
Duration	0.525	0.407	0.775	0.767	0.975

8.11.24 Hard vowels second position first iteration output (NH in noise)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.397	0.199	0.501	0.319	0.938
Height	0.918	0.413	0.449	0.663	0.872
Duration	0.588	0.272	0.463	0.437	0.935

8.11.25 Easy consonants first position (NH via vocoded speech)

Stimulus Sounds \ Perceived Sounds	B	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	46	1												1															
d	6	88																							2				
ɖ																													
ð																													
f					24																								
g																													
ɣ	5						17						6	6		4	2					2						1	
h					3			9	2				1					2	1						1				4
ħ							2		44																				
j					1					16		1					4						1					1	
k																													
l		2			7					2		43	2	9									1						
m													67	3						1									
n		2			1									21															
q															24														
r																22											1		
s					3								1				81		11										
ʂ					1		1										11	34	1										
ʃ					2												10	1	34				1						
t											1			1			1		2	31			1		1			8	
ʈ	1	1					1								2					6	33			1					
w																													
z	1	1			1			1				1	4	9		1	1	1		1			20						1
ʐ																													
ʒ											4						1								66				
ʔ																													
ʕ					2		1		1		1		2			2	1		1			1			1		29		1
θ	1				9			1						1			3										1	31	
χ					2																								70

8.11.26 Easy consonants second position (NH via vocoded speech)

Stimulus Sounds	Perceived Sounds																												
	B	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	47					1																							
d	1	37	1					1				2		1	1	1	1								1				
ɖ																													
ð																													
f					18													6											
g																													
ɣ																													
h								20	2																		1		
ħ									34																1				11
j		2					1	1	1	44	1	1	1	2		3			1			1					4		
k	1	1									82									3	4						2		
l	1	1			1					2		63		2		1													
m													22	2															
n	1				1				1			1	6	54						1									
q																													
r											1	1				69						1							
s					2		1				1						58	1	8										
ʂ					2												2	39	4										
ʃ																			47										
t																													
ʈ																					48								
w	3									1		1	2	4		4						78							
z												2				1							44		1				
ʐ	1								1					1		1								20					
ʒ		2												3			2					1	1		87				
ʔ																													
ʕ	2				1	1	2	2	23	1			1	3	1	1											80		
θ																													
χ																													

8.11.27 Easy consonants third position (NH via vocoded speech)

	Perceived Sounds																											
Stimulus Sounds	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	64	2										1	1	1		1											1		
d		22												1															
ɖ																													
ð																													
f					21											1			1										1
g																													
ɣ																													
h																													
ħ									21																		1		
j								1		84				1															
k		2						1			24	1	1			1		1		10	2								1
l	2	2			1				1	12		64		4		2													
m												1	38			1													
n													3	17															
q																													
r																													
s											1						38		8										
ʂ					3												2	16	1										
ʃ								3											20										
t																													
ʈ																					24								
w																1						45							
z																													
ʐ					1															1				20					
ʒ		1																							22				
ʔ																													
ʕ																													
θ																													
χ																													

8.11.28 Easy consonants fourth position (NH via vocoded speech)

Stimulus Sounds	Perceived Sounds																												
	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	62	6			1	1				1		1	3	5	1	4				1									
d																													
ɖ																													
ð																													
f	1	1			52						1			1		2	5	2	1	1			1					1	
g																													
ɣ																													
h	1	1						36						1															
ħ					3				31			1	1				2		1										8
j																													
k																													
l	2	3								4		118		2	1	2			2		2				1		1		
m												10	33	2															
n	5	3			1	1				3		5	5	231		13							1				3		
q																													
r	1															46					1								
s																	23								1				
ʂ					1													42					5						
ʃ																													
t		2																		22									
ʈ	1	4																		1	18								
w																													
z																													
ʐ													1											23					
ʒ		3																							18				
ʔ																													
ʕ																													
θ																													
χ																													23

8.11.29 Easy vowels first position (NH via vocoded speech)

		Perceived Sounds												
Stimulus Sounds		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
	æ	755	8	1			10	3	8	1	8		7	
	æː	3	68											
	ɑ	6	14	19						1			1	
	e													
	eː		1			23								
	ə													
	i													
	ɪ	20					1		94				1	
	o	1	14	2		5				2				
	ɔ													
	u											48		
	ʊ												24	
	ʌ													24

8.11.30 Easy vowels second position (NH via vocoded speech)

		Perceived Sounds												
Stimulus Sounds		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
	æ	389	3				28		22					
	æː	5	112	1										
	ɑ			47										
	e													
	eː	1				22			1					
	ə	4					51							
	i	1					1	188	2					
	ɪ	42		1			16	10	114					
	o													
	ɔ													
	u	6	1	1			2	1	1			55		
	ʊ													
	ʌ	14							1				1	5

8.11.31 Hard consonants first position (NH via vocoded speech)

	Perceived Sounds																											
Stimulus Sounds	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	19												4																
d																													
ɖ	9	4	7		1		1		1																				
ð																													
f					71													1											
g	8		1		1	2	3				1				2						1	4							
ɣ					1		16		2						1												3		1
h																													
ħ							1		47																				
j																													
k					1				1		62				4		1												
l																													
m													22	1					1										
n					2								4	62		2											1		
q	1						1				1				10					2	6								
r		1			1	1	4		1			1				30	1										1		1
s		1			5												143	5	13										
ʂ					5												6	32	1	1									2
ʃ																			47										
t		1			2				1								1			19									
ʈ																													
w	2																					45							
z																													
ʐ																													
ʒ		1								1									2						42				
ʔ																													
ʕ							10	7	9	1	1																57		2
θ																													
χ					12		12	2	3						1		1											3	82

8.11.32 Hard consonants second position (NH via vocoded speech)

Stimulus Sounds	Perceived Sounds																												
	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	65	4										1	12	6	1	1	1			2									
d	2	71				8						1		3	1					2					2				
ɖ																													
ð																													
f					16												5	2											
g																													
ɣ																													
h																													
ħ					1			1	20																		2		
j																													
k											16									3					3				
l	1	2		1				1		5		206	2	19	1	13							1				7		
m	1						1					1	121	10		4					1	2	1						
n																													
q															21						2								
r		1			1							1	1			221		2					8				1		
s					5												16	2											
ʂ															1		8	10	3		1				1				
ʃ																			21								2		1
t																													
ʈ	4	1			1							1	2		2					2	57								
w	7												2									14							
z																													
ʐ																													
ʒ		3												1							1				19				
ʔ																													
ʕ							8	2	2							1											57		1
θ																													
χ																													

8.11.33 Hard consonants third position (NH via vocoded speech)

Stimulus Sounds	Perceived Sounds																												
		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	45	1													1														
	d																													
	ɖ																													
	ð																													
	f					24																								
	g																													
	ɣ																													
	h																													
	ħ																													
	j																													
	k																													
	l	1	2								4		93	2	14															
	m																													
	n																													
	q																													
	r										1						30													
	s																													
	ʂ																													
	ʃ																													
	t																													
	ʈ		1																		1	20								
	w																						23							
	z																													
	ʐ																													
	ʒ																													
	ʔ																													
	ʕ																1				1							20		
	θ																													
	χ																													

8.11.34 Hard consonants fourth position (NH via vocoded speech)

Stimulus Sounds	Perceived Sounds																												
		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	37	12				1						1	5			9								1	1				
	d	14	78	3		1						1		1	1		15					1								
	ɖ																													
	ð																													
	f																													
	g	12	3	1			39							6		1	1	1				1				1				
	ɣ																													
	h																													
	ħ		1			1				22		5	1				1	7		1								1		5
	j																													
	k																													
	l		2			2			1		1		90	1	7		5		1			1								
	m	4											2	60	3															
	n																													
	q																													
	r		1				1						2	2	4		102							1				1		
	s																	10		13						1				
	ʂ																													
	ʃ																			24										
	t																													
	ʈ	1					1						1			3						17								
	w																													
	z																													
	ʐ																													
	ʒ																													
	ʔ																													
	ʕ									1			13				2											20		
	θ																													
	χ																													

8.11.35 Hard vowels first position (NH via vocoded speech)

		Perceived Sounds												
Stimulus Sounds		æ	æː	ɑ	e	eː	ə	i	ı	o	ɔ	u	ʊ	ʌ
	æ	972	2				3		8		2			
	æː	7	127	4			1							
	ɑ													
	E													
	eː													
	ə													
	I													
	ı	12					2		32		1			
	O													
	ɔ													
	U													
	ʊ													
	ʌ													

8.11.36 Hard vowels second position (NH via vocoded speech)

		Perceived Sounds												
Stimulus Sounds		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
	Æ	816	5	2			20	3	42					
	æː													
	ɑ	6	5	11			1							
	E													
	eː													
	ə	2			1		35	4	3					
	i		1					113	2					
	ɪ	16						1	77					
	o													
	ɔ													
	u													
	ʊ													
	ʌ													

8.11.37 Easy consonants first position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.999	0.72	0.72	0.218	0.951
Place	2.957	1.978	0.669	0.599	0.82
Manner	1.691	1.165	0.689	0.353	0.9
Duration	0.863	0.564	0.653	0.171	0.946

8.11.38 Easy consonants second position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.926	0.707	0.763	0.205	0.958
Place	3.088	2.357	0.763	0.683	0.876
Manner	1.97	1.556	0.79	0.451	0.935
Duration	0.834	0.686	0.823	0.199	0.979

8.11.39 Easy consonants third position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.915	0.778	0.851	0.238	0.981
Place	3.033	2.419	0.797	0.739	0.877
Manner	1.879	1.585	0.844	0.484	0.947
Duration	0.689	0.57	0.828	0.174	0.984

8.11.40 Easy consonants fourth position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.904	0.678	0.75	0.252	0.963
Place	2.095	1.256	0.599	0.467	0.753
Manner	2.051	1.425	0.695	0.53	0.873
Duration	0.554	0.164	0.295	0.061	0.911

8.11.41 Easy vowels first position first iteration (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.66	0.365	0.552	0.273	0.941
Height	0.871	0.52	0.597	0.389	0.934
Duration	0.674	0.54	0.801	0.405	0.98

8.11.42 Easy vowels second position first iteration (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.808	0.508	0.629	0.273	0.932
Height	1.272	0.747	0.587	0.402	0.888
Duration	0.965	0.772	0.801	0.416	0.97

8.11.43 Hard consonants first position first iteration output (NH via vocoded speech))

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.972	0.662	0.682	0.213	0.944
Place	2.898	2.107	0.727	0.679	0.834
Manner	1.569	1.226	0.781	0.395	0.95
Duration	0.882	0.732	0.83	0.236	0.978

8.11.44 Hard consonants first position second iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.72	0.539	0.748	0.202	0.97
Place	2.487	1.738	0.699	0.651	0.863
Manner	2.279	1.673	0.734	0.627	0.893
Duration	0.406	0.238	0.586	0.089	0.966

8.11.45 Hard consonants third position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.638	0.563	0.883	0.236	0.989
Place	2.086	1.925	0.923	0.808	0.944
Manner	1.773	1.632	0.92	0.685	0.923
Duration	0	0	0	0	1

8.11.46 Hard consonants fourth position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.992	0.032	0.032	0.015	0.543
Place	3.044	1.326	0.436	0.615	0.195
Manner	1.465	0.623	0.425	0.289	0.343
Duration	0.528	0.035	0.067	0.016	0.862

8.11.47 Hard vowels first position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0	0	0	0	0.989
Height	0.243	0.128	0.526	0.219	0.976
Duration	0.525	0.455	0.866	0.781	0.991

8.11.48 Hard vowels second position first iteration output (NH via vocoded speech)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.375	0.17	0.455	0.209	0.962
Height	0.905	0.555	0.614	0.682	0.921
Duration	0.527	0.404	0.766	0.495	0.979

8.11.49 Easy consonants first position (CI)

	Perceived Sounds																												
Stimulus Sounds	B	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	42	1															2			2									
d	1	89							1		1		1	1			1		1	1					4				
ɖ																													
ð																													
f	1				18								1							1	1	1							1
g																													
ɣ			1		1	1	30		1			1	7	3		1						1		1					
h								18	8																				
ħ								2	43						1												1		1
j										20		1	1	1			1						1						
k																													
l	1							1	1	3		63	2	2			1		1										
m						1							66	5					1	2									
n	1	2			1							1	1	12				1					1						
q	2				1										16	1					1	1							
r								1	1				1			17				1		1							2
s		1									4		1				88		2	5									
ʂ									1								4	43	1	1									
ʃ																	1		51										
t		1															3			42								2	
ʈ											2										48								
w																													
z												3					2						43						
ʐ																													
ʒ		4				4				2	2								3			1	1		59				
ʔ																													
ʕ																											47		
θ		1			2								2							5	2							37	
χ								2	4								1									1			68

8.11.50 Easy consonants second position (CI)

Stimulus Sounds / Perceived Sounds	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	47	1			1						1											1							
d		45										2	1	1			1					1							
ɖ																													
ð																													
f					9											1	3	6		1	3								
g																													
ɣ																													
h								25		1																			
ħ					1			3	46																				
j										69		3				1											1		
k	1	1									89		2				2		1	6	1						1		
l									1	1		73				1													
m	1	2		1						1			16	4															
n	3	1								4	4	1	1	53		2							1						
q																													
r	5											1				68					1	1							
s																	68	2	1	3			1						
ʂ					1												7	42		1									
ʃ									1								1	1	46										
t																													
ʈ	1				1			1			1									3	41								
w	1											5	1	1			1			1		92							
z																													
ʐ	1	1			5						1			1				1						11					
ʒ		5				1										1	1		1	2			2		89				
ʔ																													
ʕ	4	3					1	1	21	1			1	3			1		1								84		
θ																													
χ																													

8.11.51 Easy consonants third position (CI)

		Perceived Sounds																												
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	63	1											1							3							1		
	d		22																											
	ɖ																													
	ð																													
	f					25																								
	g																													
	ɣ																													
	h																													
	ħ								3	17										2								2		
	j										81		2		3															
	k											32						1			4									
	l										2		92	1								1								
	m												1	46	1											1				
	n														18															
	q																													
	r																													
	s									1								43												
	ʂ																	3	19		1									
	ʃ									1										22										
	t																													
	ʈ	1										1									2	15								
	w												2										43							
	z																													
	ʐ		1			5																			8					
	ʒ		1																		1					20				
	ʔ																													
	ʕ																													
	θ																													
	χ																													

8.11.52 Easy consonants fourth position (CI)

		Perceived Sounds																												
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	63	2										2	1	12		3								1					
	d																													
	ɖ																													
	ð																													
	f		1			37			1				1	1	1		2	15	1		1				2				1	
	g																													
	ɣ																													
	h								41						1		1						1							
	ħ								2	47																				
	j																													
	k																													
	l		2										130		8											1	1			
	m		1										10	34			3													
	n	2	1				1		1				7	2	252		4	1					1				1	2		
	q																													
	r												1		2		46													
	s																	22												
	ʂ					1							1				1	17	26		1									
	ʃ																													
	t																				23									
	ʈ													1	2						5	16								
	w																													
	z																													
	ʐ		1															1							24					
	ʒ	1																2		1						20				
	ʔ																													
	ʕ																													
	θ																													
	χ					1			4	1																				15

8.11.53 Easy vowels first position (CI)

		Perceived Sounds												
		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
Stimulus Sounds	æ	799	5	2	1	1	5	4	16		2	1	5	5
	æː	2	73											
	ɑ	1	3	45					1					
	e													
	eː	1				24		1						
	ə													
	i													
	ɪ	3				1	1	1	112	1				4
	o									26				
	ɔ													
	u	3					1					44	1	
	ʊ	1							1			7	16	
	ʌ	3						1						20

8.11.54 Easy vowels second position (CI)

		Perceived Sounds												
Stimulus Sounds		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
	æ	434	1	5	2		7	10	9	1	1	1		
	æː	8	114						1			1		
	ɑ	1	1	48			1							
	e													
	eː					20		4						
	ə	8	1	1			32	2	12					1
	i	3						190	3					
	ɪ	12					5	19	152	1	2			
	o													
	ɔ													
	u											75		
	ʊ													
	ʌ	3												13

8.11.55 Hard consonants first position (CI)

	Perceived Sounds																												
Stimulus Sounds	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	22	1															1										1		
d																													
ɖ																													
ð	10		9									1	1							1				1	1				
f		1			52					1			3				6	1	1	2	2		1		1				
g		4				18					1				1				1										
ɣ					1	1	14	1	1				1																3
h																													
ħ								2	46											1							1		
j																													
k					5	1			4		53	1			4		2		1	2		1							
l																													
m													21	3															
n	1	5				1				1			1	57			3			3									
q						2			1		1				16					1	4								
r		2	1		2	2	1	1	1						6	21	1					1			1		2		
s													13				136	6	4	7			1		3				
ʂ													2				8	37	1						2				
ʃ	1										1		1				2		46										
t						1					3				1	1				19									
ʈ																													
w											1		1					1		1		46			1				
z																													
ʐ																													
ʒ		2		1		1											3		1						42				
ʔ																													
ʕ		1					1	2	2				1						1						1	1	80		
θ																													
χ							8	3	10		1		1				1			1					1				98

8.11.56 Hard consonants second position (CI)

	Perceived Sounds																												
Stimulus Sounds	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	61	5		2	2				1			2	10	4		9					2			1					
d	3	70			1	6						1	4	8							3		1		2				
ɖ																													
ð																													
f					2												14	6	1	1	1								
g																													
ɣ																													
h																													
ħ									14								9			1							1		
j																													
k		1		1							14						1			5					1				
l	3				1			1	2	12		227	6	7		2		2		1	2		1				2		1
m	4								1				125		1	5	1		1	1					1		1		
n																													
q						1					2	1			14					2	2								1
r	8	6	1		5		1	1	2			13	7	1		180	4	1	2	1	3		4		2		1		
s											2						21	3											
ʂ																	2	23	1										
ʃ																			24										
t																													
ʈ	1	1												4		2				5	63								
w												3				1						22							
z																													
ʐ																													
ʒ		1																	1				1		21				
ʔ																													
ʕ		4					2	6	2	1				3		1	2							1			50		
θ																													
χ																													

8.11.57 Hard consonants third position (CI)

	Perceived Sounds																												
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	40	1			2	1							1	1							1			1					
	d																													
	ɖ																													
	ð																													
	f					19								1			1													
	g																													
	ɣ																													
	h																													
	ħ																													
	j																													
	k																													
	l	1					1			1	6		101		3															
	m																													
	n																													
	q																													
	r												1				26									1				
	s																													
	ʂ																													
	ʃ																													
	t																													
	ʈ																					24								
	w																						24							
	z																													
	ʐ																													
	ʒ																													
	ʔ																													
	ʕ									1				2													1	16		
	θ																													
	χ																													

8.11.58 Hard consonants fourth position (CI)

		Perceived Sounds																											
Stimulus Sounds		b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
	b	32	7									1	5	18	2		9	1					1			1		1		1
	d	2	78				1			1			2	3	8		7				1							1		
	ɖ																													
	ð																													
	f																													
	g	9	3			1	34						1	9	1		1				1	3								
	ɣ																													
	h																													
	ħ								3	33		2																2		
	j																													
	k																													
	l	1	2								3	1	73	3	2		6				5	3								
	m	1				1							1	61																
	n																													
	q																													
	r		2				1			2	1		5	1	2		99	1									5			
	s																	21												
	ʂ																													
	ʃ										1						1	2		18						1				
	t																													
	ʈ													1		1						20					1			
	w																													
	z																													
	ʐ																													
	ʒ																													
	ʔ																													
	ʕ												7	1	2		1				1						2	28		
	θ																													
	χ																													

8.11.59 Hard vowels first position (CI)

		Perceived Sounds												
		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
Stimulus Sounds	æ	955	10	6		1	4	2	28	1	4	4	5	10
	æː	14	120	5		1			1				1	
	ɑ													
	e													
	eː													
	ə													
	i													
	ɪ	2		1		1	3	4	37				1	
	o													
	ɔ													
	u													
	ʊ													
	ʌ													

8.11.60 Hard vowels second position (CI)

		Perceived Sounds												
		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
Stimulus Sounds	æ	798	19	8			22	5	30		1	4	2	2
	æː													
	ɑ	1	1	22										
	e													
	eː													
	ə	6					29	4	7			1		
	i	1	2					115	1					
	ɪ	19		2			6	7	57		1		1	1
	o													
	ɔ													
	u													
	ʊ													
	ʌ													

8.11.61 Easy consonants first position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.989	0.422	0.427	0.123	0.848
Place	3.006	1.817	0.605	0.53	0.683
Manner	1.799	1.028	0.571	0.3	0.847
Duration	0.706	0.326	0.462	0.095	0.868

8.11.62 Easy consonants second position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.957	0.773	0.807	0.23	0.97
Place	3.13	2.075	0.663	0.617	0.747
Manner	2.062	1.593	0.773	0.474	0.927
Duration	0.668	0.235	0.353	0.07	0.843

8.11.63 Easy consonants third position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.901	0.766	0.85	0.225	0.979
Place	3.023	2.475	0.819	0.728	0.878
Manner	1.888	1.728	0.915	0.509	0.977
Duration	0.655	0.345	0.527	0.102	0.933

8.11.64 Easy consonants fourth position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voicing	0.877	0.703	0.802	0.273	0.974
Place	2.054	1.357	0.661	0.527	0.875
Manner	2.092	1.537	0.735	0.597	0.906
Duration	0.472	0.346	0.733	0.134	0.974

8.11.65 Easy vowels first position first iteration (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.665	0.487	0.733	0.338	0.966
Height	0.87	0.639	0.735	0.444	0.956
Duration	0.683	0.525	0.769	0.365	0.972

8.11.66 Easy vowels second position first iteration (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.803	0.544	0.678	0.279	0.955
Height	1.267	0.85	0.671	0.436	0.929
Duration	0.965	0.697	0.722	0.357	0.951

8.11.67 Hard consonants first position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.97	0.561	0.578	0.189	0.916
Place	2.973	1.97	0.663	0.665	0.805
Manner	1.53	0.926	0.605	0.313	0.881
Duration	0.883	0.592	0.67	0.2	0.947

8.11.68 Hard consonants first position second iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.728	0.478	0.657	0.199	0.944
Place	2.497	1.47	0.589	0.611	0.805
Manner	2.272	1.441	0.634	0.599	0.849
Duration	0.409	0.266	0.65	0.11	0.952

8.11.69 Hard consonants third position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.639	0.485	0.759	0.212	0.971
Place	2.099	1.848	0.881	0.809	0.921
Manner	1.749	1.473	0.843	0.645	0.935
Duration	0	0	0	0	0.996

8.11.70 Hard consonants fourth position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.63	0.406	0.645	0.19	0.945
Place	2.438	1.464	0.6	0.684	0.798
Manner	2.149	1.21	0.563	0.565	0.795
Duration	0.347	0.295	0.849	0.138	0.993

8.11.71 Hard vowels first position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0	0	0	0	0.963
Height	0.243	0.14	0.577	0.271	0.952
Duration	0.519	0.33	0.637	0.639	0.962

8.11.72 Hard vowels second position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0.385	0.168	0.437	0.225	0.94
Height	0.913	0.471	0.516	0.629	0.903
Duration	0.534	0.375	0.701	0.5	0.955

8.11.73 CV consonants first position (CI)

	Perceived Sounds																												
Stimulus Sounds	b	d	ɖ	ð	f	g	ɣ	h	ħ	j	k	l	m	n	q	r	s	ʂ	ʃ	t	ʈ	w	z	ʐ	ʒ	ʔ	ʕ	θ	χ
b	48	35	1	1	34	4	2				4	1	1			2	3			8	2	1	3	2	2	2	1	1	4
d	10	113		4	7	1			1	1	2					1	7			14			1	1	1	1	1	2	
ɖ																													
ð																													
f																													
g	7	44		4	3	36			1	2	22	2	2				5		2	17				1	3	5		2	
ɣ	4	13	3	2	9	4	34	5	1	1	4	2	1	3	5	3	2		1	3	5	6	4	6		1	3	4	23
h																													
ħ	1				5	1	1	5	142				1				4			2			1			1			4
j	2	20		1	4			2	3	94	3	5	11	1		1	3		2	2		3	3		2	3	2	1	1
k	2	11			3	1		4	2		95		1				9		9	26					3			1	2
l																													
m	7	5		3	2		1	1	1	1		7	120	23						1			1						1
n																													
q																													
r	4	7	3	2	17	1	5	5	1	3	2	12	2	2	2	23			2	3	6	37	1	4		3	2	3	8
s					5	1			2								157		3	2			2						
ʂ																													
ʃ					2												4		165	3									
t	1	11			14			2	2		10		1	1			17		6	97				1	3	1		3	3
ʈ																													
w	9	7		6	4	2		1		1	2	1	11	2		1			1	2		110		2	1	1			
z	3	15	1	1	4		1			3	2	3	3	4		1	14		1	5		1	99		1			3	
ʐ																													
ʒ																													
ʔ																													
ʕ	2	1	1		3	3	5	5	3	1		1	1		2	1	2		1	2	1	2		2		6	105		1
θ																													
χ		3			10	1	2	5	21	1	1				1	1	6		3	1		1	1			1		1	108

8.11.74 CV vowels first position (CI)

		Perceived Sounds												
		æ	æː	ɑ	e	eː	ə	i	ɪ	o	ɔ	u	ʊ	ʌ
Stimulus Sounds	æ	1331		14				5	3		1	3	1	
	æː													
	ɑ													
	e													
	eː													
	ə													
	i	40			10		1	1276	8			4	2	
	ɪ													
	o													
	ɔ													
	u													
	ʊ													
	ʌ													

8.11.75 CV consonants first position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Voice	0.963	0.417	0.433	0.199	0.844
Place	3.001	1.385	0.461	0.66	0.636
Manner	1.926	0.77	0.399	0.367	0.761
Duration	0.708	0.395	0.558	0.188	0.932

8.11.76 CV vowels first position first iteration output (CI)

FEATURE	INPUT	TRANS	%TRANS	TRANS/TI	%CORRECT
Place	0	0	0	0	0.99
Height	1	0.865	0.865	0.984	0.976
Duration	1	0.806	0.806	0.918	0.969