

**The Development of a Behavioural Test Battery in Auditory Processing for Maltese
School Children**

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Dedication

*I dedicate this research to
my dearest mother and father whose constant
affection, love, and encouragement kept me going till the end.*

I owe them a debt of gratitude!

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Abstract

This research investigates the auditory processing skills of bilingual Maltese children. The purpose of this study is to identify trends on a novel assessment battery of auditory processing targeted at the paediatric Maltese population. A total of 130 children participated. The sample included 101 typically developing children and 29 presenting with a diagnosed neurodevelopmental disorder (clinical group). The typically developing children's performance on the assessment battery was compared in terms of 'age', 'gender', 'primary language', 'geographic region' and 'school type'. The performance of this group was further compared with that of a clinical group. Reliability and validity studies were carried out on the developed and modified subtests in the assessment battery. A factor analysis of the tool highlighted two factors under which the subtests fall: those incorporating linguistic stimuli and those using non-linguistic stimuli. A regression analysis revealed predictors of the subtests in terms of the demographic factors as well as other subtests within the tool. The result outcomes are discussed with respect to related studies carried out on other paediatric populations. Overall, there were no significant differences in the performance of the TD group when divided in their categorical variables, but significant differences in the performance of the TD and clinical groups on the APD questionnaire and assessment battery. This study is the first step to research on auditory processing in Malta. It provides a basis to further research, where a deeper analysis into the performance of specific clinical populations can be carried out, and an initial guide to clinical professionals working with this population.

Keywords: auditory processing, assessment, children, bilingual

Abbreviations

AAA = American Academy of Audiology

ABR = Auditory brainstem response

AC = Auditory cortex

ADHD = Attention deficit hyperactivity disorder

ANSD = Auditory neuropathy spectrum disorder

AP = Auditory processing

APA = American Psychiatric Association

APS = Auditory processing skills

ART = Acoustic reflex thresholds

ASD = Autism spectrum disorders

ASHA = American Speech Hearing Association

Ath = Smallest gap detected

BC = Between channel

BM = Basilar membrane

BSA = British Society of Audiology

CANS = Central auditory nervous system

CC = Corpus callosum

CF = Characteristic frequency

CHAPPS = Children's Auditory Processing Performance Scale

CN = Cochlear nucleus

DD = Dichotic digits

DDFA = Dichotic digits focused attention

DDFR = Dichotic digits free recall

DLD = Developmental language disorder

DPT = Duration patterns test

DSM = Diagnostic and Statistical Manual of Mental Disorders

eNWRT(n) = English nonword repetition test in noise

eNWRT(qu) = English nonword repetition test in quiet

FAPC = Fisher's Auditory Problems Checklist

FPT = Frequency patterns test

GDT = Gap detection threshold

GIN = Gaps in noise

IC = Inferior colliculus

ICD-10 = 10th revision of the International Statistical Classification of Diseases and Related Health Problems

ILD = Interaural level differences

IQ = Intelligence quotient

ITD = Interaural time differences

K-S = Kolmogorov-Smirnov

LI = Language impairment

LitD = Literacy difficulties

MGB = Medial geniculate body

MMN = Mismatch negativity

mNWRT(n) = Maltese nonword repetition test in noise

mNWRT(qu) = Maltese nonword repetition test in quiet

NSO = National statistics office

NWRT = Nonword repetition test

OAEs = Otoacoustic emissions

ODD = Oppositional defiant disorder

PAC = Primary auditory cortex

PL = Primary language

QCAP = Questionnaire of (central) auditory processing

RA = Research assistant

RD = Reading difficulties

REA = Right ear advantage

SAD = Separation anxiety disorder

SD = standard deviation

SIFTER = Screening Instrument for Targeting Educational Risk

SIT = Sentence imitation test

SLI = Specific language impairment

SNR = Signal to noise ratio

SOC = Superior olivary complex

SPD = Spatial processing disorder

S-W = Shapiro-Wilk

TAPS-R = Test of Auditory Perceptual Skills—Revised

TEOAEs = Transient evoked otoacoustic emissions

TD = Typically developing

TP = Temporal processing

WC = Within channel

WHO = World Health Organisation

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¹ The researcher was previously 'Calleja'. 'Calleja' merged into 'Calleja Tabone' and later became 'Tabone' during the course of this research. Therefore, the names 'Calleja', 'Calleja Tabone', and 'Tabone' refer to the same person.

Presentations related to this research

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Chapter 1. Introduction

1.0 Chapter overview

This thesis describes the development of a test battery for auditory processing skills (APS) in Maltese children. It explains the steps taken in the selection and construction of the tools and the assessment on 101 typically developing children and 30 children diagnosed with various neurodevelopmental disorders². This chapter commences by introducing the concept of auditory processing and the relevance of choosing it as a topic of this research. An overview of the state-of-the-art in related research is provided here. The chapter continues by delineating the language situation in Malta and its relevance to the effects on the auditory processing of speech signals. Finally, the research aims and objectives are addressed.

1.1 What is auditory processing?

The process of ‘hearing’ includes more than the transduction of an acoustic signal into neural impulses in the ear (Bamiou, Musiek, & Luxon, 2001). These impulses are transmitted to the brain by the auditory nerves. Auditory processing is the ability of the central nervous system to perceptually process auditory information coming from the auditory channels, and encompasses the mechanism of electrophysiological auditory potentials stemming from the neurobiological activity responsible for this processing of information. It involves both the detection of sound and its transmission through the auditory pathways to the brain (Yalcinkaya, Muluk & Sahin, 2009). Various studies have indicated similarities and overlap between auditory and speech processing (e.g. Benasich et al., 2006;

² Throughout this thesis the term ‘neurodevelopmental disorders’ is used to describe a communication disorder that includes various currently separate markers (such as language, literacy, attention and behavior difficulties) as described by Moore and Hunter (2013).

Joanisse & Gati, 2003; Zaehle, Wustenberg, Meyer, & Jancke, 2004). The conscious perception of auditory signals, both speech and non-speech, occurs in the auditory cortex, with the primary sensory cortical areas being the region where initial perception occurs. This also has been found to be the site where bottom-up and top-down processing³ come together (Moore & Hunter, 2013).

1.2 Why obtain data on auditory processing skills in the Maltese population?

The purpose of an assessment in auditory processing (AP) is to diagnose difficulties within various aspects of APS. The reported high rates of co-morbidity with other neurodevelopmental disorders such as developmental language disorder⁴ (Miller & Wagstaff, 2011; Ferguson, Hall, Riley & Moore, 2011), attention deficit (Amin, 2013; Huang et al., 2012) and literacy difficulties (Sharma, Purdy & Kelly, 2009; Fraser, Goswami & Conti-Ramsden, 2010) warrants the importance of assessing the various skills in auditory processing. Of relevance to the Maltese population, who are typically early sequential bilinguals (Grech & McLeod, 2012), studies have demonstrated that bilingual individuals perform differently to monolingual individuals on AP tests. Following reports that there is a positive correlation between the volume of Heschl's gyrus (which is located in the primary auditory cortex) and the proficiency in perceiving contrasts in speech sounds emanating from a foreign language (Golestani, Molko, Dehane, LeBihan & Pallier, 2007; Wong et al., 2007), interest was shown in finding out whether early exposure to more than one language resulted in an effect on Heschl's gyrus. Ressel et al. (2012) compared Spanish-Catalan bilingual speakers exposed to both languages from early childhood to matched Spanish monolinguals.

³ The concepts of bottom-up and top-down processing will be explained in the literature review (section 2.5)

⁴ The term 'developmental language disorder' (DLD) has recently replaced the earlier used terms 'language impairment' and 'specific language impairment', following a consensus study involving a panel of experts (Bishop, Snowling, Thomson & Greenhalgh, 2017). In light of this very recent change, these terms will be used interchangeably throughout this thesis.

They found that the average volume of Heschl's gyrus and the gray matter volume was larger in the bilingual group, demonstrating that the early learning of a second language is a causal factor in the larger size of the auditory. Another study investigated performance of simultaneous Brazilian Portuguese-German bilingual speakers and sequential Brazilian Portuguese-Italian bilingual speakers on dichotic listening tasks (Greesele, Garcia, Torres, Santos, & Costa, 2013). The authors found differences between both the simultaneous and sequential bilingual speakers when compared to the monolingual control group. Overall, both bilingual groups performed significantly better than the monolingual group, indicating that exposure to more than one language results in a positive influence on dichotic listening skills. The outcomes of this study also showed a difference between the sequential and simultaneous bilingual speakers, with the former obtaining significantly better scores.

To date, there have been some small scale studies (mainly unpublished dissertations) in the field of AP on the Maltese population. No normative data have been collected as yet. Some studies supervised by the researcher have investigated specific areas of auditory processing. For example, Cassar (2014) revealed results on the Gaps-in-Noise test (Musiek, 2003) in a paediatric typically developing sample. On the other hand Balzan and Tabone (2017) obtained data on temporal processing tests in the geriatric population, while Hales (2016) investigated reliability measures of these temporal tests. Pace and Calleja's (2015) study was specific to APS in young adult musicians. There have also been studies interested in the APS of children with different neurodevelopmental disorders. Tabone (2015) investigated the performance on AP tasks in children with Attention Deficit Hyperactivity Disorder (ADHD). Azzopardi's (2015) study examined auditory and language processing skills in children with a developmental language disorder (DLD). The outcomes of these studies relevant to this research will be discussed in the chapters to come. One limitation which seems to be common to these studies is that no normative data are available with

which their data can be compared, resulting in the authors resorting to the use of small control group samples. In turn, this study aims to establish trends on the performance of typically developing children on a battery of auditory processing assessments. The outcomes of this study would be beneficial to professionals within both the educational and clinical fields. For example, with the existing knowledge that children exhibit difficulties with speech perception and understanding in noisy situations typical of a classroom setting (Klatte, Lachmann & Meis, 2010; Valente, Plevinsky, Franco, Heinrichs-Graham & Lewis, 2012), the study outcomes regarding how Maltese children perceive speech in the presence of background noise could encourage educational bodies to improve the acoustic environment in the class rooms (such as through the installation of assistive listening devices in the classroom). Clinical professionals, on the other hand, would be given the basis to diagnose APD and devise appropriate intervention plans, such as the provision of assistive listening devices that would aid in complex acoustic environments, as well as auditory training intervention.

1.3 Language patterns used in Malta

Behavioural assessment batteries of AP frequently include stimuli of both linguistic and non-linguistic content (Bamiou & Luxon, 2008; Iliadou et al., 2017; Ptok, Miller, & Kühn, 2016). In light of this, an understanding of the language situation unique to this population is key in the development of an assessment battery for AP.

The Maltese Islands are positioned in the middle of the Mediterranean Sea. The Maltese language is divided into a Semitic stratum, with a Romance superstratum, and

English adstratum⁵ (Vella, 2003). The lexicon has been found to consist of 70% Arabic, 20% Italian, and 10% of loaned words - mainly English (David, 2007). There has been a history of interaction with various groups of people of different languages and cultures, who had come to the islands to rule or form colonies there (Brincat, 2011) and in turn, brought about a mixture linguistic and cultural influence. Both the Maltese and English languages are used on the Maltese Islands to varying degrees. In fact, since Malta has obtained independence from British rule (back in 1964), both languages hold an official status, with English being given the co-official status of second national language of the Maltese Islands by the Constitution of the Republic of Malta (Camilleri Grima, 2013).

In Malta, all children are exposed to simultaneous or sequential bilingualism. Simultaneous bilinguals experience both languages from the time they are born while sequential bilinguals would have acquired at least some competence in one language before being exposed to the second language. The majority have been found to be early sequential bilinguals (Grech & Dodd, 2008), where their second language is introduced during the first five years of life (Kohnert & Bates, 2002). Most Maltese children are dominant in either Maltese or English, with the largest part exposed predominantly to Maltese (Grech & Dodd, 2008). In fact, Maltese *is* the dominant language in the majority of the Maltese population. This has been established through a number of surveys. For example, Sciriha and Vassallo (2006) showed percentages of 98.6% and 96.2% (in the years 2001 and 2005 respectively) from 500 participants who claimed Maltese as their native language. A similar finding is evident from the latest report on the Census of Population and Housing (National Statistics Office, 2014). This survey, which was carried out in 2011, revealed that out of 358 924

⁵ In linguistics, a **stratum** is a language that influences, or is influenced by another. A **substratum** is a language which has lower power or prestige than another, while a **superstratum** or **superstrate** is the language that has higher power or prestige. Both substratum and superstratum languages influence each other, but in different ways. An **adstratum** refers to a language that is in contact with another language in a neighbor population without having identifiably higher or lower prestige.

Maltese respondents, 97.6% spoke Maltese well and 1.3% spoke it averagely. On the other hand it was also found that 65.3% of the respondents spoke English well and 16.6% spoke it averagely.

The age and amount of exposure to the second language varies, depending on the context of the family and community, though once respondents start attending school, they are likely to be exposed to both languages (Grech & Dodd, 2008). Indeed, the Maltese educational system employs both the Maltese and English languages throughout primary and secondary education, to the point that a bilingual educational system is encouraged (Camilleri Grima, 2013) and implemented throughout all school-types across Malta, being state, church or independent schools (Ministry for Education and Employment, 2015). This would indicate that while the Maltese language seems to be used most commonly for purposes of oral communication, English is often used for writing purposes (Vella, 2013). It provides a means of enhancing education, and attracting business and tourism, which is advantageous for cultural enrichment and improvements to the economy (Scicluna, 2011). These data demonstrate that different levels and dimensions of bilingualism exist. While individuals may therefore be proficient in two languages, they could possess different levels of mastery in the domains of language (such as phonology, morphology and syntax) and the modalities (such as the oral and written mode of communication) (Rodriguez, Carrasquillo, & Lee 2014).

This introduction attempted to highlight the following key points:

- To acquaint the reader with the topic of AP.
- Explain the necessity of obtaining data related to AP in the Maltese population
- Shed light on the language patterns used in Malta and their relevance to AP assessment.

With these in mind, the next sections present the reader with the research aim and objectives.

1.4 Research Aim

Given the gap in scientific and linguistic knowledge specific to this population, the aim of this research is to primarily develop an assessment battery sensitive to diagnosing difficulties in auditory processing skills for Maltese children. It is a further aim to examine the effect of age, primary language, location, and school status on auditory processing abilities. In order to address these aims the following objectives are tackled.

1.5 Research objectives

Objective 1: Construction and Development

- a) To construct a comprehensive assessment battery of auditory processing.
- b) To develop a questionnaire of auditory processing skills: The Questionnaire of (Central) Auditory Processing (QCAP).
- c) To develop the language specific subtests as part of the assessment battery.
- d) To obtain trends for the Maltese population in children aged between 7;00 and 9;11 years.

Objective 2: Description

- a) To describe the development of the language-specific subtests used to collect the data.
- b) To describe the auditory processing skills of Maltese children in terms of age, gender, primary language, location, and school type (state / church / independent), and socio-economic status.

Objective 3: Measurement

- a) To measure the children's performance on all tests within and across groups.

- b) To measure reliability of the developed and modified tests:
 - a. The QCAP: test-retest reliability, equivalence reliability, split-half and internal consistency.
 - b. Nonword repetition in noise and in quiet: test-retest, intra-rater and inter-rater, and equivalence reliability.
 - c. Gaps-in-noise test: test-retest reliability, inter-ear reliability, inter-list reliability
 - d. Duration patterns test: test-retest reliability.

- c) To measure the validity of the developed tools and adapted tools by retesting participants on parallel measures, through content and face validity, convergent and concurrent validity, statistical conclusion and internal validity, and through clinical validation - comparing typically developing children's performance and children with reported neurodevelopmental disorders.

Objective 4: Comparisons and correlations

- a) To compare the auditory processing performance on all tests within and across groups⁶:
 - i. Age
 - ii. Gender
 - iii. Primary language
 - iv. Location
 - v. School type

⁶ The AP performance among these participants was further compared across socioeconomic status. However this was done at a later stage following examiner recommendations in the MPhil to PhD transfer, the results of which have been published.

- vi. Clinical group (all presenting with a diagnosed neurodevelopmental disorder and reported listening difficulties).
- b) To determine predictors of each test through a regression analysis, in terms of the independent variables mentioned in point (a) as well as in terms of the other subtests.
- c) To correlate the performance between each of the AP subtests.
- d) To correlate the QCAP outcome with each subtest.
- e) To correlate the AP subtests with the language processing subtests (nonword repetition tests and the Sentence Imitation Test (SIT))
- f) To compare the APS in typically developing children with those of the clinical group.

Objective 5: Qualitative Investigation

- a) To analyse error patterns in the Maltese and English nonword repetition tests in quiet in terms of the error patterns found in:
 - a. Single consonants:
 - b. Consonant clusters:
 - c. Consonant sequences:
 - d. Vowels:
 - e. Syllable structure: addition and reduction

} substitutions, omissions and additions
- b) To analyse error patterns in the SIT for Maltese and English responses separately, in terms of:
 - a. inaccurate imitations in three categories: no imitation, ungrammatical imitation, and grammatical inaccurate imitation.
 - b. Imitation accuracy of : content words, function words and inflections

Objective 6: Corroboration

- a) To corroborate the performance of Maltese children on the internationally established assessments (specifically: Dichotic Digits Test, Frequency Patterns Test, Duration Patterns Test, Gaps-in-Noise) with previous research obtaining norms and trends in other populations.

In the following chapters the researcher will attempt to address these objectives through the testing of children on the constructed assessment battery and interpretation of the results that emerge. The next chapter (Chapter 2) offers a comprehensive literature review. The construction, development and description of the assessment battery are described in Chapter 3. The reliability and validity of the tool is explained in Chapter 4, while the measurement, comparison and results are given in Chapter 5. The outcomes of these results are then discussed at the end of each respective chapter. Chapter 6 presents the reader with a qualitative analysis of the language processing tests, followed by a discussion of this analysis.

Chapter 2. Literature Review

2.1 Chapter overview

Speech and language is a major characteristic that distinguishes the human race from other living beings. Humans use language as a means of communication; a portal through which thoughts, emotions, and needs are shared via discussions and conversations. Common to all human languages are certain universal features, such as the way words are joined together to form the meaning of a complex expression (Hauser, Chomsky, & Fitch, 2002). In addition to these are phonological and prosodic characteristics, and syntactic rules specific to each language (Cutler, Mehler, Norris, & Segui, 1983).

Some children are referred for audiometric evaluation due to the fact that they appear to have hearing difficulties. Yet, when tested they are found to have normal hearing sensitivity (Iliadou et al., 2017; Sharma, Purdy, & Kelly, 2009). Very often, these children are portrayed by parents and teachers as having difficulties following multiple instructions or attending conversations, and being increasingly distracted in the presence of background noise (Iliadou et al., 2017; Witton, 2010). It has also been reported that these children take longer to understand simple directions presented verbally, at times misunderstand what has been told to them, or seem to have selective hearing (Johnson, Benson & Seaton, 1997). These difficulties often result in both education and social difficulties (*American Speech-Language-Hearing Association (ASHA), 2005; British Society of Audiology (BSA), 2007*). It has been suggested that children presenting with these difficulties could be diagnosed with Auditory Processing Disorder (APD) (*American Academy of Audiology; AAA, 2010; ASHA, 2005; BSA, 2007; Iliadou et al., 2017*).

This chapter will review the literature on AP, and the skills thought to be related. In line with the aim and objectives of this research, the chapter is structured as follows:

1. Organisation of the auditory system and its underlying physiology
2. Language processing
3. The auditory aspect of speech perception
4. Bottom up and top down cognitive processes
5. Defining auditory processing disorder (APD)
6. Assessment of auditory processing skills
7. Auditory processing skills in relation to age, gender, bilingualism, geographic region and school type
8. Comorbidity of APD

2.2 Organisation of the auditory system and its underlying physiology

The human auditory system is a complex structured system of nuclei and cortical areas that receives and interprets sound signals (Malmierca & Hackett, 2010). Its function is to detect the very quick changes of air pressure along the dynamic range of hearing (20 to 20,000Hz) (Smith, 2000), hence bringing out meaningful information, such as speech and communication, from the acoustic environment (Asari, 2007).

Sounds are initially collected through the outer ear, which plays a role in the localisation of sound and amplification of the higher frequencies. As the acoustic signal enters the middle ear the low frequency sounds are attenuated, resulting in an even greater sensitivity of the ear to the mid and high frequency acoustic signals (Hayes, Ding, Salvi & Allman, 2013). The sound signals consequently enter the inner ear where they are converted into a chain of action potentials – the suitable organisation needed for the nervous system, where they are conveyed to subcortical and cortical areas for additional processing (Asari, 2007). This permits detection, discrimination, localisation, and the separation of compound sound sources – all necessary for successful communication through speech and language,

where in turn meaningful perceptual representations of the signal are combined with learning and memory (Brugge, 2013).

In the next sections the ascending auditory pathway is briefly discussed, commencing at the level of the hair cells in the cochlea to the auditory cortex.

2.2.1 Hair Cells and auditory nerve fibres. As the acoustic signal moves along the basilar membrane of the cochlea, the sound waveform is split into specific frequency components – tonotopy (Bear, Connors, & Paradiso, 2007). This breakdown into the respective frequency constituents is determined by the cochlea's mechanical properties and anatomical arrangement, so that every frequency element causes basilar membrane (BM) vibrations at exact points, where resonance occurs. Each mechanosensory hair cell on the BM reacts to only a narrow frequency bandwidth and enhances its energy, thus improving frequency analysis supported by the tonotopical organisation of the cochlea (Asari, 2007). The cochlear hair cells convert the mechanical vibration induced by the sound waves into electrical signals through depolarisation and hyperpolarisation. Neurotransmitters are released, and in turn the auditory nerve fibres are activated thus transmitting the electrical signal to the auditory cortex (Hayes et al., 2013). This allows the auditory nerve fibres to convey information about the occurrence, the amplitude and the timing of a sound signal (Harrison, 2001; Trevino, Coleman, & Allen, 2010).

2.2.2 Cochlear Nucleus (CN). The signal's ascent towards the auditory cortex is complex with several decussating fibres and nuclei synapse points. The beginning of what is regarded as the central auditory pathway is the cochlear nucleus complex (Wu, Stefanescu, Martel & Shore, 2014), where nerve fibres present in the inner ear synapse. The CN receives information from the ipsilateral auditory nerve fibres. The incoming data are bundled into parallel pathways (Cant & Benson, 2003) and relayed to both ipsilateral and contralateral superior olivary nuclei (Kandel, Schwartz, & Jessel, 2000), which is the first relay station where binaural hearing takes place, to ultimately converge in the inferior colliculus (Lee, 2013). This suggests that spectrotemporal coding is already active at this level (Oertel, 1991). Tonotopical organisation is also maintained, with each nerve fibre exhibiting excitation and inhibition thresholds to stimuli of a specific frequency (characteristic frequency (CF)); which is linked to the frequency resonance area along the BM from where the fibre derives (Brugge, 2013).

2.2.3 Superior Olivary Complex (SOC). The SOC receives the binaural inputs from the CN, where they first meet each other, and sends outputs through the lateral laminiscus to the inferior colliculus (Konishi, 2003). It plays a significant role in sound localization (Tortora & Derrickson, 2008) by making use of binaural cues such as interaural level differences (ILD) - allowing the accurate encoding of the intensity differences of a sound arriving to each ear, especially for high frequency sounds (Caird & Klinke, 1983), and interaural time differences (ITD), which are important cues for the localisation of low frequency sounds. This site is thought to receive input from both ipsilateral and contralateral sides but with a varying "wire length" from each side, resulting in an internal delay for signals to reach the SOC (Asari, 2007). Hence, the convergence of the signals at the SOC from each side concurs only once the difference in these latencies corresponds precisely with the arrival time difference of the sounds in the two ears (Palmer, 2004).

2.2.4 Inferior Colliculus (IC). The ascent of the fibres along the auditory pathway continues through the IC, located in the midbrain. At this level a tonotopical map is also preserved and sensitivity to interaural delay is evident (Skottun, Shackleton, Arnott, & Palmer, 2001). Thus, specific nuclei in the IC may characterise midbrain specialisations for the processing of spectral cues used in the localisation of sound (Davis, Ramachandran, & May, 2002). The cells in the IC exhibit robust binaural preferences to rich stimuli like changes in amplitude or frequency but not to unvaried acoustic stimuli (Kandel et al., 2000; Smith, 2000). Some neurons use binaural stimulation in order to attain spatial selectivity, while other neurons can achieve this in monaural conditions (Davis et al., 2002). Furthermore, some neurons in the IC have been found to respond to spectral changes, which underlie recognition of specific phonemes and speech intonation (Fitch, Miller, & Tallal, 1997).

2.2.5 Medial Geniculate Body (MGB). The medial geniculate body (MGB) forms part of the auditory thalamus and characterises the thalamic relay from the IC up to the primary auditory cortex (AC), and is the final subcortical station before the auditory signals reach the AC (Suga & Ma, 2003). Previously, the MGB has been looked at as simply a “relay station” for sound inputs reaching the auditory cortex. However, evidence suggests that the specific thalamic circuits in the MGB can be important in establishing the emotional content of the auditory stimuli, such as the neurons projecting directly to the amygdala, modulating its activity. This projection is believed to bring about the preparation of emotional reactions to acoustic stimuli (Farb & LeDoux, 1997; LeDoux, Sakaguchi & Reis, 1984).

The MGB consists of three principal sections distinguished on the basis of anatomical features and coding properties (Read, Miller, Escabi, Schreiner, & Winer, 2004). The ventral part responds primarily to narrowband acoustic signals. This is the only division part

exhibiting clear tonotopic organisation. The dorsal and medial sections respond mainly to complex sounds (Hu, 2003). In addition, the cells in the MGB also show multi-modal responses, where along with the auditory signals, they receive visual and somatosensory inputs (Komura, Tamura, Uwano, Nishijo, & Ono, 2005). The characteristics of orderly periodicity typically present in the IC do not seem to occur in the MGB (Moore, Fuchs, Rees, Palmer & Plack, 2010). It has also been found that the processing of pitch present in the IC is reduced significantly in the MGB (and even further in the AC) (Moore et al., 2010). This is true for both pure tone synchronisation (Liu, Palmer, & Wallace, 2006; Wallace, Anderson, & Palmer, 2007) and amplitude modulated tone synchronisation (Bartlett & Wang, 2007). It has been suggested that the MGB is important in the conversion of pitch, as transferred from the IC, to a code denoting an extracted form of the pitch (Moore et al., 2010).

2.2.6 Primary Auditory Cortex (PAC). The primary auditory cortex is the first cortical area that gathers the signals from the auditory thalamus and processes these inputs to make sense of them (Asari, 2007). Unlike other sensory systems, where the input is received by the cortex more directly, auditory inputs are processed and altered substantially before reaching the PAC - beginning from the transduction from auditory to electrical signals at the level of the hair cell receptors in the cochlea; the encoding of these signals as streams of action potentials at the level of the vestibulo-cochlear nerve; and the transmission and further processing and complex encoding of the sounds through the brainstem, midbrain, and thalamus up to the PAC (King & Schnupp, 2007).

While some investigators claim that the PAC functions as a ‘collector’ of auditory signals (Nelken & Bar-Yosef, 2008), the dominant model explains the PAC as an *acoustic analyser* (Weinberger, 2012) where the signals’ physical parameters are processed from binaural inputs areas (Miller, Escabi, Read, & Schreiner, 2001). Most recently, the ‘auditory

object theory' has been put forward, which suggests that the PAC responds to combined sounds not in an additive manner, but in its constituent parts (i.e. auditory objects). These objects are then used by other parts of the brain to guide behaviour responses, such as listening to music, responding to a person's voice and sound localisation (Nelken, Bizley, Shamma & Wang, 2014). The reader is referred to Nelken et al. (2014) for an in-depth explanation of the 'auditory object theory'. The auditory neurons are vastly heterogeneous in receptive field sizes and demonstrate varied response patterns (Hromádka & Zador, 2007). These include the distribution of frequency (tonotopic organisation) and intensity and amplitude variation, locus in space, the duration of a stimulus, spectral bandwidth and the rate of repetition (Wu, Tao, & Zhang, 2011; Weinberger, 2012). This analysis occurs in the 'primary' areas of the AC (the primary and anterior auditory fields, and the posterior, ventral, and ventroposterior auditory fields) (Schreiner, Mendelson, & Sutter, 1992; Mendelson Schreiner & Sutter, 1997; Eggermont, 1998).

Other areas of the PAC, such as the secondary auditory cortex and the suprasylvian fissure, are not tonotopic. These are typically characterised by broader tuning curves and thought to play a role in processing communication signals and non-spectral information (Rauschecker & Tian, 2000). Different areas still, such as the limbic related and posterior ectosylvian fields, receive and process multi-modal data from auditory, visual, and visceral inputs (Kayser, Petkov, Augath, & Logothetis, 2005).

Studies have also investigated the plasticity of the PAC in relation to learning and memory (Weinberger, 2012). It has been suggested that the PAC could be involved in directing attention (Fritz, Elhilali, M., David, & Shamma, 2007) and perceptual learning (Dahmen & King, 2007). Early studies such as Galambos, Sheatz, and Vernier (1956) have demonstrated that when an auditory signal is associated with another event (such as a positive or negative consequence), there are changes observed electrophysiologically in the auditory

cortex. Hence there is evidence that auditory learning would psychologically mould the meaning of sounds, enabling the comprehension and neural storage thereafter of sound (following its detection and analysis) (Weinberger, 2012).

2.2.7 Corpus Callosum (CC). The CC is the largest white matter structure in the human brain that connects the left and right cerebral hemispheres (van der Knaap & van der Ham, 2011) via approximately 200 million fibres (Aboitiz, Scheibel, Fisher, & Zaidel, 1992). While these fibres are already present at birth, their myelination continues during the course of puberty, revealing developmental morphological changes (Luders, Thompson & Toga, 2010). With its contribution to information processing of cortical areas, the CC is considered to be involved in the lateralisation of brain function, i.e. the distribution of information processing to the left or right cerebral hemisphere. In turn, the CC plays an important role in the information exchange between cortical areas concerned with unilateral representations, such as the processing of speech and language in the left hemisphere (van der Knaap & van der Ham, 2011). The CC is also seen as a mechanism through which one hemisphere influences the opposite hemisphere via slow and fast inter-hemispheric transmission (Ringo, Doty, Demeter & Simard, 1994)

The dichotic listening technique is an experimental non-invasive paradigm that investigates this functional cerebral lateralisation. When different acoustic stimuli (most commonly verbal) are presented simultaneously to each ear, there typically emerges superior reports of the right ear input (a right ear advantage (REA)). This highlights the left-hemisphere dominance for the processing of speech and language (Westerhausen & Hugdahl, 2008). The REA has been explained through two theoretical models, both linking dichotic listening skills to the functional integrity of the CC. One is referred to as the ‘structural model’ (Kimura, 1967). This model suggests that the REA occurs due to differences in

strength in the ipsilateral and contralateral projections from the CN of each ear up to the AC. The stronger contralateral projections result in a stronger representation in the opposite hemisphere to the ear receiving and transmitting the signals. While the right ear input is transferred directly to the left hemisphere for speech processing, signals transferred through the left ear are primarily received in the right hemisphere and then transferred via the corpus callosum to the left, to then undergo the speech processing. This additional ‘callosal relay’ step (Zaidel, 1983) causes a slight delay of information, resulting in the weaker left ear report (Westerhausen & Hugdahl, 2008). The other model is known as the ‘attentional model’ (Kisbourne, 1970). It proposes that typically, the left hemisphere is automatically activated in expectation of an incoming verbal signal. This in turn results in an attentional preference to the contralateral side so that the signal reaching the right ear is processed quicker. The CC then plays a role in balancing out the level of activation found between the two hemispheres (Kinsbourne, 2003). This model also suggests that the preferred ear could reveal the direction of the attentional bias and therefore the hemisphere that was first activated (Westerhausen & Hugdahl, 2008).

2.3 Language processing

The areas of the brain involved in language processing are situated in the inferior frontal and temporal cortices with the left hemisphere being dominant (Friederici, 2012). These cortices are linked through the ventral and dorsal pathways (Rauschecker & Scott, 2009). The ventral pathway has been found to facilitate auditory-to-meaning mapping and the construction of syntactic structure (Friederici, Bahlmann, Heim, Schubotz, & Anwander, 2006) while the dorsal pathway sustains auditory-to-motor mapping (Hickok & Poeppel, 2007) and syntactic processing of complex sentences (Wilson et al., 2011).

The PAC (described in section 2.2.1.6) is housed in Heschyl's gyrus (HG) – an area which also supports the processing of language. The left middle sector of the superior temporal gyrus (lateral to HG) supports the processing of phonemes (Leaver & Rauschecker, 2010), while the portion anterior to HG facilitates the processing of words received auditorily (DeWitt & Rauschecker, 2010), via extremely fast (40 to 90ms) detection ability of morphological structures, used to build up words of a specific language (Herrmann, Maess, Hahne, Schröger, & Friederici, 2011). At this level, the recognition between words versus nonwords can be executed (Friederici, 2012). The processing of the syntax in a language occurs slightly later (120 to 150ms after data on the word category is formed) in the anterior superior temporal cortex (Herrmann et al., 2011), while lexical-semantic data are processed rapidly after a word is recognised. The detailed processing of the more complex language present in sentences and phrases is beyond the scope of this study. For an extensive description of this higher order processing the reader is referred to Obleser, Meyer, & Friederici, (2011), Friederici (2012), and Chou, Huang, Lee, & Lee, (2014).

It has been proposed that the processing of language occurs through high precision complex auditory processing (Obrig, Rossi, Telkemeyer, & Wartenburger, 2010). Language processing has been analysed in terms of specialised auditory characteristics such as spectral and temporal processing of auditory signals (Schonwiesner, Rubsamen, & von Cramon, 2005; Wang et al., 2012) and slow and fast variations of the auditory stimuli (Boemio, Fromm, Braun, & Poeppel, 2005; Overath, Zhang, Sanes, & Poeppel, 2012). However, studies have shown that the acquisition of language is not solely based on auditory processing but on an amalgamation of bottom up and top down processing, where the competence of language aids in the understanding of ambiguous sounds (Obrig et al., 2010).

2.4 The auditory aspect of speech perception

Various theories related to speech perception have been proposed. In general, these theories suggest that speech perception is based on the acoustic signal and processing in the auditory system, with initial perception lying at the sub-phonemic level and involving acoustic analysis (Tuomainen, 2009). The Auditory Enhancement Theory (Diehl, Kluender, & Walsh, 1990) proposes that the properties of a speech sound determine the articulatory patterns, where the acoustic signal confers the information necessary for perceiving speech. This theory contrasts with gestural theories (Lieberman & Mattingly, 1989), which suggest the contrary – that articulatory gestures provide information salient to speech perception. Diehl et al. (1990) propose that a language contains specific phonological features which are enhanced perceptually to add to the detection of a unique characteristic. An example of this can be seen in the [voice] distinctive feature, which requires low frequency energy fundamental to acoustic-phonetic properties that contribute to the specific perceptual feature (Tuomainen, 2009). A similar theory to the Auditory Enhancement Theory is the Fuzzy-Logic Model of Perception (FLMP) (Massaro, 1987). This theory proposes that in addition to the auditory modality, other modalities supplement the sensory information. For example, the auditory property of a syllable can be enhanced by the lip movements. The independent modalities (such as auditory and visual) would then be integrated together to bring out a final value (Tuomainen, 2009). A third theory on auditory speech perception is the interactive spoken word recognition model: TRACE (McClelland & Elman, 1986). This theory suggests that auditory input corresponds to three linguistic units: phonetic characteristics, phonemes and words. Information flows in a bi-directional manner; bottom-up and top-down, so that an acoustic signal is processed in the form of acoustic-phonetic characteristics.

2.5 Bottom up and top down models of auditory processing

A current debate that in turn influences the definition of auditory processing is whether it should be looked at as a bottom up or top down process (Wilson, Heine, & Harvey, 2004). As it stands there are two main theories underlying developmental auditory processing disorder (APD). One hypothesis suggests that APD is caused by impaired bottom-up sensory processing, including the ear and the central auditory nervous system (CANS) (Moore & Hunter, 2013). This hypothesis has been described as the pathway model of auditory processing and defines it as being sound driven (Wilson et al., 2004). The bottom up approach focuses on how sounds are manipulated at different levels of the CANS and suggests that the sound properties determine the higher-level representations and constructions (Chermak & Musiek, 1997).

The second hypothesis proposes that the difficulties with auditory processing result from top-down effects of cortical cognitive processing areas, which would in turn influence language processing, attention and memory, and indirectly affect auditory perception (Moore & Hunter, 2013). This hypothesis defines auditory processing as knowledge- or concept-driven, so that the sound processing is controlled by higher-level processing and consequently sounds are interpreted (Chermak & Musiek, 1997). This position was adopted by network models of auditory processing (Wilson et al., 2004), which focus on the combination of sound, meaning and intention and go beyond the auditory pathway (Friel-Patti, 1999).

Although bottom-up and top-down theories diverge in their approach to auditory processing, they are not entirely incompatible (Friel-Patti, 1999; Moore & Hunter, 2013). The amalgamation of both functions enables the processing of auditory information (Bellis, 2003). While bottom-up processing is crucial for auditory perception, top-down influences are necessary to regulate and control the incoming signal (Moore & Hunter, 2013).

Therefore, as bottom-up processes provide information related to incoming sounds, top-down processes integrate sounds with an individual's experiences and expectations. This in turn aids bottom-up processes to be informed of both new auditory signals and data that are mismatched with a current hypothesis about that sound (Wilson et al., 2004). Alain, Arnott and Picton (2001) find that bottom-up processes as well as top-down processes influence auditory scene analysis, a process which describes the separation of individual sounds in "natural-world situations" by the auditory system. Such sounds are then interconnected and overlapped in time while their components are done so in frequency. Theories of brain function propose that 'perception' is worked out in a hierarchical manner at different time scales, driven by both bottom-up and top-down flow of information (Friston, 2008). Balaguer-Ballester, Clark, Coath, Krumbholz, and Denham (2009) demonstrate this hierarchy in the computation of pitch. They show that the higher areas enhance the temporal scale over which information is integrated in lower areas. So depending on whether the stimuli are slow or fast, different temporal scales are induced. A recent study using electrophysiological methods (Shuai & Gong, 2014) supports this theory. Their results demonstrated that speech perception depends on language experience, which emerges through top-down processing, and the instant auditory input, deriving from the bottom-up processing. Top down processes adapt sounds conforming to the listener's experiences, while bottom-up processes simultaneously acquaint the listener with new sounds and information which conflict with the ongoing hypotheses concerning the message.

These findings suggest that there is a complex interrelation between bottom-up and top-down pathways, posing difficulties in separating each process in a clinical assessment (Wilson et al., 2004; Moore & Hunter, 2013).

2.6 Defining auditory processing disorder (APD)

Auditory processing disorder (APD) has increasingly gained recognition in the field of audiology over the past two decades (Ludwig et al., 2014). Three subtypes have been referred to in the BSA (2018) position paper. The first one is the developmental APD. It describes a deficit presenting in childhood, where normal hearing and no other known aetiologies risk factors are evident. This type of APD is most relevant and applies to this research. Secondary and acquired APD have been described to refer to cases in which the APD occurs in conjunction with a peripheral hearing impairment or known post natal event respectively (BSA, 2018).

APD has been described as a mixture of unrefined listening skills causing poor speech perception. This is especially the case in noisy environments, which pose a heavier challenge to the individual (Rosen, Cohen & Vanniasegaram, 2010). These difficulties are evident despite the presence of normal hearing (de Wit et al., 2016). Yet, APD is still lacking of an underlying theoretical model (Ferguson, 2014). To date, there is no 'gold standard' for diagnosing APD, despite statements that the currently used diagnostic auditory processing test batteries are the best available as a gold standard approach (Iliadou et al., 2017). There is no universally accepted audiological assessment battery for APD and, although it is included in the International Classification of Disorders version 10 World Health Organisation manual under H93.25 (1993) and in the forthcoming ICD 11 beta version (Iliadou et al., 2017), there is no agreed definition of APD (Kamhi, 2011; Tabone et al., 2016; Wilson & Arnott, 2013). Linked with this, reports on APD prevalence have been varied. Some studies show estimates of prevalence in the paediatric population ranging between 2 and 10% (Bamiou, Musiek & Luxon, 2001; Hind et al., 2011). When combined with other learning disabilities, the prevalence has been found to increase to between 30 and 50% (King, Warrior, Hayes & Kraus, 2002; Ramus, 2003).

The initial suggestion of auditory processing disorder dates back to the 1950s when Myklebust (1954) came up with the observation that some young children have difficulties with auditory perception in the absence of a language disorder and peripheral hearing loss (Kamhi, 2011; Miller, 2011; Moore, Ferguson, Edmondson-Jones, Ratib, & Riley, 2010). Researchers then took a psychoeducational approach⁷ to the processing of sounds (Kamhi, 2011), where a popular assessment was used to assess auditory skills, namely the *Illinois Test of Psycholinguistic Abilities* (ITPA; Kirk, McCarthy, & Kirk, 1968). This assessment, which focused on auditory perceptual skills including auditory reception, association, sequential memory, closure, and sound blending, was the basis of the psychoeducational approach of language development throughout the 1960's and 70's (Kamhi, 2011). The rationale was that if the specific auditory perceptual skills contributing to language-related and academic difficulties can be detected, they can be rectified (Miller, 2011). This approach corresponded with Lahey's (1988) outlook towards language impairment through form, content, and use. It focused on restricted and specific skills which researchers in this area believed were required for comprehension and expression of language and literacy (Miller, 2011).

However, it was not until 1974 that the term APD (auditory processing disorder) was used – in a meeting held by the *American Speech, Language, and Hearing Association* (Moore, et al., 2010). Soon after, an audiological approach to APD became popular, where specific assessments of auditory perception started to be developed, and until present some of these tests are still used as part of the core assessment battery in the diagnosis of APD (Jerger, 2009). This resulted in the psychoeducational approach to APD becoming less focused-upon, and replaced by assessments of cognition, attention, and language skills (Kamhi, 2011).

⁷ The psychoeducational approach tries to balance out educational and clinical effects (Edwards, 1984).

In the mid-1970s the debate regarding the link between auditory perception and language impairment commenced (Rees, 1973; Tallal & Piercy, 1973). For example, Tallal and Piercy's (1973) study indicates that children with developmental language disorders have weak discrimination of rapidly changing non-verbal stimuli and suggested an association between auditory perceptual processing and language. On the other hand, Rees (1973) queries the claim that auditory processing deficits could cause language and academic difficulties. She points out that there seems to be a very fine line between auditory and language processing, and it is not of diagnostic importance to look for underlying auditory deficits present in language disorders since it is doubtful that language and reading development skills could be explained solely by auditory processing skills. The author further questions the actual existence of CAPD and suggested the possibility that auditory deficits could simply be a manifestation of a language disorder (Rees, 1981).

Following the application of psychoeducational and audiological approach, interest in combining the two emerges. Bellis (1996) attempts to amalgamate the skills assessed in the ITPA (Kirk et al., 1968) with tests of auditory perception. This amalgamated approach is still sought after as part of assessment batteries for auditory processing (Geffner & Ross-Swain, 2007).

Jerger (2009) identifies a third approach to auditory processing research – the language processing approach. This approach examines the interaction between speech and language processing, and the effect of top-down processing (such as language knowledge and cognition) on the auditory stimulus (Miller, 2011). Researchers who follow this approach regard auditory processing as merely one portion of a global processing of language and emphasise the importance of conceptual and language knowledge in language processing (Kamhi, 2011). This approach has led researchers, such as Medwetsky, (2006), to suggest

the term 'spoken language processing disorder' to describe children with difficulties in processing speech.

In the latest technical report, ASHA (2005) describes APD as a disorder in the perceptual processing of speech and non-speech auditory signals in the auditory nervous system, causing weak performance skills in one or more of the following: discrimination of auditory information, recognition of auditory patterns, temporal processing skills, auditory performance in the presence of competing sound stimuli, and auditory performance when acoustic information is degraded. The extent to which the perception of an auditory signal is affected depends the specific auditory processes that are weak as well as the complexity and acoustic makeup of the auditory data to be processed (Price, Thierry, & Griffiths, 2005). The ASHA report also acknowledges the fact that although the definition of APD delineates the most prominent weaknesses in sensory *auditory* processing, one cannot exclude that sensory processing in the central nervous system is supported by language and cognitive skills, as has been shown through several electrophysiological studies (e.g Bajo, Nodal, Moore, & King, 2010; Clark, Rosen, Tallal, & Fitch, 2000; de Boer & Thornton, 2008; Irving, Moore, Liberman, & Sumner, 2011; Neville, Coffey, Holcomb, & Tallal, 1993; Tallal, Merzenich, Miller & Jenkins, 1998).

This causes ambiguity in the understanding as to *what* should be included under the term APD. For instance, Mody, Studdert-Kennedy, and Brady (1997) hold that speech is processed in a different way to other sounds, resulting in the possibility of an individual to have a perceptual impairment specific to speech. The 2005 definition provided by the *British Society of Audiology* (BSA) seems to build on Mody et al.'s (1997) claims in defining APD as an impairment involving non-speech sounds (but not solely). Thus, it recommends that APD needs to be diagnosed through non-speech tests in addition to the speech-based tests. Subsequently, if an auditory impairment is present only in speech processing or phonological

categorisation it cannot be considered as APD. However, with results from international studies (Moore et al, 2010, Watson & Kidd, 2009) as well as a local study (Tabone et al., 2016) revealing no significant or consistent relation between outcomes on simple stimuli non-speech psychoacoustic tasks and the reported listening difficulties, this approach on APD does not prove to be a good link between the reason for referral and the diagnostic assessment (Moore, Rosen, Bamiou, Campbell, & Sirimanna, 2013). In a more recent definition put forward by the BSA position statement of 2011(b) and 2018, APD includes the “poor perception of both speech and non-speech sounds”, resulting in poor listening abilities. Griffiths (2002) had proposed that auditory processing is defined as the development of sound objects prior to the acquisition of meaning (semantic processing). This definition could comprise an impairment in phoneme discrimination (Dawes & Bishop, 2009). Dawes and Bishop (2009) also define APD as an impairment in the processing of auditory signals, yet this may present in combination with other cognitive and perceptual impairments.

These variations within definitions of APD make it unclear as to where to draw the line between an auditory or linguistic impairment. The evidence of this complex processing has led researchers to query whether diagnosis of APD through complete specificity to the auditory modality is required and acceptable (DeBonis & Moncrieff, 2008). Cacace and McFarland (2005, 2013) suggest a definition based on ‘modality-specificity’, in an attempt of avoiding the ambiguity of what is (or is not) APD. The authors define it as a modality-specific perceptual dysfunction not caused by peripheral hearing loss. They further hold that being a modality-specific perceptual dysfunction, APD should be distinct from similar difficulties arising from impairments in cognitive, language, and/or attention skills. This proposal follows their earlier work relating to the concept of modality specificity (McFarland & Cacace, 1995), contrasting auditory test performance with visual test performance and in turn providing evidence of divergent and construct validity (McFarland & Cacace, 2012).

The argument put forward by these authors has been questioned (Musiek, Chermak & Bellis, 2005). While Musiek et al. (2005) do agree to a certain extent with McFarland and Cacace's statement that "CAPD should be distinguishable from cognitive, language-based, and/or supramodal attentional problems in which modality-specific perceptual dysfunctions are not expected" (2005, p.113), they suggest that rather than defining it as *exclusively* specific to the auditory perceptual modality, APD should fall as *primarily* modality specific.

The most recent definition provided by the BSA (2018)⁸ provides a broad approach to the origins of APD, suggesting that the symptoms occur as a result of impaired neural function within the afferent and efferent pathways of the CANS, along with its related top-down modulation (including vision, as well as the cognitive functions of speech and language, attention, executive function, fluid reasoning, memory and emotion). This definition implies that APD frequently occurs in conjunction with (and could be a contributing factor of) the primary disorders of those systems. The BSA (2018) hold that "APD may thus include both auditory and cognitive elements" (p. 6).

2.7 Assessment of auditory processing skills

The lack of 'gold standard' for diagnosing APD could result in great variability across centres assessing for APD (BSA, 2011) and difficulties in meeting the requisites needed to make a strong test (Keith, 2009). Ferguson (2014) describes these requisites to include good construct validity (Johnson, Bellis & Billiet, 2007) and test-retest reliability (Cacace & McFarland, 2005), a high sensitivity and specificity (Wilson & Arnott, 2013), standardisation (Dawes & Bishop, 2009) and cut-off scores (Keith, 2009) of the tests in a specific population; especially in subtests incorporating linguistic content.

⁸ The purpose of the new BSA position statement (2018) was to provide and update to (rather than replace) the BSA (2011) position statement. Thus, throughout this text both position statements will be referred to.

Professionals who encounter individuals queried for having APD in their daily clinical routine are requesting a set of guidelines to help them best manage this population. This has encouraged numerous research studies to strive in obtaining strong evidence of the disorder and its presenting symptoms in order to further recommend the best diagnostic criteria and intervention strategies (BSA, 2011a). This differential diagnosis is especially important due to converging findings that APD may co-exist with other impairments (Dawes & Bishop, 2008; Ferguson & Moore, 2014; Ferguson et al., 2011; Miller & Wagstaff, 2011; Sharma et al., 2009; Witton, 2010). In light of this, the BSA (2007) recommends that a multidisciplinary assessment be carried out in the diagnosis of APD, including: (1) Detailed audiometric testing that detects peripheral hearing loss and differentiates between similar presenting disorders to APD, such as Auditory Neuropathy Spectrum Disorder (ANSO); (2) An assessment battery of auditory processing. The *American Academy of Audiology* (AAA, 2010) recommends that assessments of auditory processing are primarily behavioural. The *Canadian Interorganizational Steering Group for Speech-Language Pathology and Audiology* (CISG; 2012) suggests that prior to commencement of the assessment battery a behavioural questionnaire is also given to care givers, speech-language pathologists and educators as an aid in determining whether further assessment of auditory processing is warranted. The outcomes of questionnaires might help bring out the functional impact of the APD, emphasising a child's listening difficulties. They can help the audiologist with the choice of tests to be administered, and the interpretation of the assessment battery. However, they have not been found as predictors of APD assessment outcomes and therefore it is not recommended that they are used alone to determine whether APD is present (W. Wilson et al., 2011).

The BSA (2011b) suggest both speech (linguistic) and non-speech (non-linguistic) auditory signals should be used as part of the auditory processing assessment battery. This

recommendation was also commended in guidelines published by ASHA (2005) and the AAA (2010). According to these associations, an assessment battery should include the sub categories of auditory processing, each targeted at dysfunction of the different neuroanatomical regions along the central auditory nervous system (CANS) (Johnson, Bellis, & Billiet, 2007), such as dichotic listening tests, temporal processing and patterning tests, artificially degraded speech, binaural interaction, as well as the use of electrophysiological measures. The downside of this, however, is that an increased amount of tests could imply a greater chance of a child performing poorly on one, and misinterpreted as a deficit if the entire assessment battery results are not taken into consideration (Dawes & Bishop, 2009). Therefore, a more condensed assessment battery, limited to non-speech auditory stimuli is proposed by others (Dawes & Bishop, 2009; McArthur, 2009), possibly following the BSA (2005) definition APD being an impairment specific to non-speech sounds. This idea is discarded after contradicting research (e.g. Moore et al, 2010; Tabone et al., 2016; Watson & Kidd, 2009) emerged. Bamiou Campbell, and Sirimanna (2006) propose that assessment should also include clinical observation of the child in various listening environments, and a speech and language assessment. In fact, a survey conducted by Emanuel, Ficca and Korczak (2011) reveals that 33% of audiologists carry out a classroom observation, where children might experience greater difficulty, as part of their APD screening assessment prior to administering an APD assessment battery. The BSA also commends the inclusion of a screening assessment of language, and further endorses screening of auditory memory and attention as part of a multidisciplinary approach. This was suggested in light of research studies indicating possible overlap between these impairments (Rosen, 2009), which could in turn cause a misdiagnosis and incorrect management of these children (BSA, 2011a).

In a recent argument put forward by Dillon, Cameron, Glyde, Wilson and Tomlin (2012), APD is considered through a different perspective. Contrary to suggestions by Dawes

and Bishop (2009) and McArthur (2009), Dillon et al., (2012), these authors emphasise the importance of investigating the difficulties individuals find in understanding *speech* in difficult listening conditions. These authors suggest assessment of APD through a hierarchical approach centred on listening difficulties related to speech situations. They claim that this approach would improve clinical efficiency.

The problems of APD assessment driven by a minimum test battery have also been reported by Emanuel et al. (2011), who recommend that assessment be based on the individual's case, and take into consideration any related attributes (e.g. chronological and mental age, attention levels, fatigability, and language ability) of the individual that could have an influence on the test performance (AAA, 2010).

ASHA (2005) states that in order to diagnose a person as having APD, he or she must perform poorly (at least two standard deviations below the mean) on two or more sub-tests in the assessment battery or perform very poorly (at least three standard deviations below the mean) on one sub-test. The BSA (2011) does not state any specific diagnostic criteria, but holds that APD is characterised “by poor perception of both speech and non-speech sounds” (p. 3), which would automatically entail that an individual must perform poorly on two sub-tests; one speech-based and one non-speech-based test (Wilson & Arnott, 2013).

Various factors need to be considered in the compilation and administration of an APD assessment battery. One factor is the age of the children being tested. The majority of behavioural assessments require testing to start at 7 years of age due to the fact that in younger children there is great variability of brain function, resulting in difficulties to interpret the results (Whitelaw & Yuskow, 2006). Maturational effects in the central auditory pathway are recorded until children are aged about twelve years (Moore et al., 2010). Younger children might be unable to understand and follow the directions linked to a task, resulting in potentially unreliable results. Likewise, when assessing children with diagnoses

of other disorders, their developmental age, language and cognition skills should not be ignored since they could be functioning similarly to younger children (Fong, 2016). Of clinical importance is the time factor. The assessment battery should not take too much time to administer, especially since each task can be rather taxing. Because children usually have a shorter attention span and fatigue more easily when compared with adults, an assessment battery that is complete within 45 to 60 minutes is desirable (AAA, 2010). Frequent breaks and consistent reinforcement also help keep children motivated to participate in each task. In fact, Silman, Silverman and Emmer (2000) found that children tend to perform better with reinforcement.

The areas of assessment for auditory processing skills to be used in this study, as have been reported in the literature and acknowledged within the guidelines of the BSA (2011a,b; 2018), ASHA (2005) and AAA (2011), are reviewed in the next sections.

2.7.1 Dichotic Listening tests. Speech communication is resistant to interference, allowing individuals to maintain their attention on a specific speech target and understand its contents in the presence of competing speech signals (Ding & Simon, 2012). Dichotic listening refers to this ability to selectively attend to one sound while ignoring other competing sound signals (Ross, Hillyard & Picton, 2010). This skill is necessary when one is exposed to a multispeaker environment. Through dichotic listening, individuals can direct their attention to one conversation and disregard any other voices heard simultaneously. Though interestingly, should a person outside of the focus of auditory attention mention the individual's name, his or her attention is often still captured (Wood & Cowan, 1995). This is possible when an individual selectively listens to one speaker via top-down, cognitively-controlled information processing focused on the attended channel (Bozicas et al., 2014). Simultaneously, any irrelevant auditory signals are suppressed. Yet, a significant amount of

information is still processed at unattended levels (Winkler, Czigler, Sussman, Horvath & Balazs, 2005). Imaging studies identified the superior temporal gyrus to be greatly involved in the processing of concurrent speech signals (Scott, Rosen, Beaman, Davis & Wise 2009), in which the auditory cortex is able to select and amplify the low-frequency neural correlates of the attended speech signal (Kerlin, Shakin & Miller, 2010), hence selecting specific sensory information (Schroeder & Lakatos 2009).

The primary aim in developing dichotic listening tasks is to investigate bottom-up automatic information processing (Bozikas et al., 2014). However, the numerous studies revealing top-down controlled processing involved in this listening skill (e.g Lawo, 2014, Ocklenburg et al., 2016; Tallus, Soveri, Hämäläinen, Tuomainen, & Laine, 2015; Westerhausen, Bless, Passow, Kompuss, & Hugdahl, 2015) suggest an interaction between bottom-up perceptual factors and top-down cognitive factors in auditory language information processing (Hugdahl & Westerhausen, 2016). Electrophysiological recordings during a dichotic listening task show that the auditory cortex tracks the temporal modulations of the attended speech signal more strongly than the unattended one (Ding & Simon, 2012). Falkenberg, Specht, and Westerhausen's (2011) fMRI study on dichotic listening highlighted the interaction between top-down control and attention processes with bottom-up sensory input. Similarly to Ding & Simon (2012), their study revealed an enhancement of the stimuli coming from the attended ear and suppression from the non-attended ear. The authors also showed that changes in the inter-aural intensity difference influences the ear advantage. So that, while it is typical for a dichotic listening task to result in a right ear advantage (more correct responses for the right ear; Noffsinger, Martinez, & Wilson, 1994) (based on left hemispheric lateralisation for the processing of language; Westerhausen & Hugdahl, 2008), this can be manipulated through changes in the bottom-up stimuli. The use of cognitive-

control⁹ functions in regulating speech perception is thought to be crucial to language acquisition during childhood and compensation for sensory decline in older individuals, (Westerhausen et al., 2015), warranting the importance of assessing this skill.

There are various dichotic listening tasks available, offering different types of stimuli, including nonsense syllables, digits, monosyllabic words, and spondaic words¹⁰ and sentences (Zenker et al., 2007). Studies have found dichotic digits to be good stimuli since performance on this test seems to be relatively unaffected by cochlear hearing loss provided that hearing thresholds are controlled for (Barajas, Suarez, Fernandez, & Zenker, 2005). This test has also shown good test-retest reliability in listeners of various ages (Strouse & Hall, 1995). With Malta being a bilingual country, and with English being used for most academic subjects, all Maltese bilingual children would be fully familiar with digit auditory stimuli presented in English.

Reliability studies related to the Dichotic Digits Test. Various studies have been carried out to obtain normative data on the DDT (Musiek, 1983), as well as to examine whether it meets the criteria for detecting disorders of the CANS (Musiek, 1983; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991). Specifically, the authors are interested in finding out whether the DDT is sensitive to brainstem and cerebral auditory disorders, while being resistant to mild peripheral hearing losses. They further examine the reliability and validity of the tool and its simplicity in terms of ease of understanding and completing the task. The outcomes of these studies are a mean % of 96.5 (LE) and 97.7 (RE) in 45 normal hearing adults. This study also highlights results for individuals with a cochlear loss (mean % of 92.5 and 94.2 in the LE and RE respectively), and in individuals with a CNS lesion (mean % of 60.0 and 83.6 in the LE and RE respectively). Based on these results the author recommends

⁹ Miller and Cohen (2001) define cognitive control as the formation, maintenance, and realisation of internal goals. It is often associated with executive attention, that is, the ability to focus on a task in the presence of interfering stimuli (Hugdahl et al., 2009).

¹⁰ Spondaic words consist of two-syllable words that have equal stress on each syllable (Gould & Beasley, 2014)

a cut-off percentage of 90% to differentiate between normal and abnormal performance in individuals with normal hearing levels, while a cut-off point of 80% is suggested in individuals with a cochlear loss. The results also indicated that the tool was sensitive test in the assessment of central auditory dysfunction.

A second study was carried out as a development of Musiek's (1983) research. The aim is to further analyse the sensitivity of the tool to detect pathology of the CANS, assess for test-retest reliability, and to report follow-up validity data of the previous research (Musiek et al., 1991). This study examines the performance on the DDT in three groups: normally-hearing individuals with confirmed lesions of the CANS, individuals with a mild cochlear loss and no neurological pathology, and individuals with both pathology of the CANS and a hearing loss. Results demonstrate that 75% of the individuals with CANS dysfunction but normal hearing obtained abnormal results on the DDT. 72.2% of the subjects with both CANS pathology and a cochlear loss performed below the suggested cut-off point. This is compared with the results obtained in Musiek's (1983) study, where 75% of individuals with CANS dysfunction and normal hearing performed poorly. On the other hand, only 2 out of 30 subjects with solely a cochlear loss are found to obtain abnormal results in one or both ears, with mean scores obtained being 91.0 and 94.9% for the left and right ears respectively. As a result of these findings the authors suggest that this tool is equally sensitive to a positive CANS pathology in patients with a mild to moderate loss as is in normally hearing individuals when the adjusted cut-off point of 80% is used. The results obtained by a similar study (Speaks, Niccum, & van Tassel, 1985) show consistent results with these studies, where the DDT scores are not significantly affected in individuals with a cochlear loss.

Musiek et al's (1991) study further executes a statistical analysis to compare the groups with a cochlear loss and those with a central lesion and found statistically significant lower scores ($p < 0.01$) in the subjects with a CANS pathology. Test-retest reliability testing is

performed on four individuals with CANS lesions and resulted in a similar outcome between the two tests ($r=0.77$).

2.7.2 Temporal processing tests. Auditory temporal processing (TP) refers to the ability of the auditory system to decipher the dynamic durational features of a sound signal within a time interval (Musiek et al., 2005). TP occurs when time related aspect changes are discriminated along the sound wave. Such processing has been reported as fundamental to speech (verbal stimuli) and music (non-verbal stimuli) as the temporal order of acoustic elements is necessary for the comprehension of the message (Marculino, Rabelo & Schochat, 2011). TP encompasses the detection of a sound source, followed by the determination of its pitch, the perceptual separation of consecutive sound signals, and the discrimination of variations in duration and pitch (Phillips, 1995). The processing of verbal information encompasses the processing of short and very quick changes in auditory stimuli (Samelli & Schochat, 2008). The processing of temporal information (including characteristics such as signal duration and frequency, interval and sequencing of the stimulus), enables the auditory system to perceive the subtle and rapid changes intrinsic to speech sounds. Such changes include voice onset time, timing of vocal fold vibration with the release of air, consonant-vowel combinations (Wright, Buonomano, Mahncke, & Merzenich, 1997; Bellis, 2003; Shinn, Chermak & Musiek, 2009), syllable and phoneme temporal structure, and prosodic information, like pauses, rate and duration of speech segments (which play a crucial role for the understanding of semantic cues) (Buonomano & Karmarkar, 2002). These skills also play an important role in the perception of musical rhythm and periodicity (Phillips, 2002). Temporal processing can be divided into temporal integration and masking, temporal ordering or sequencing, and temporal resolution (Marculino, Rabelo & Schochat, 2011).

2.7.2.1 Auditory temporal integration and masking. Auditory temporal integration is an important process exhibited by the brain in which coherent percepts from sensory events are constructed. This process essentially depends on the way memory traces are shaped in terms of integrating past with present experiences. It is significant to auditory processing, where sensory input is picked up in both a serial and parallel manner (Mustovic et al., 2003).

Temporal masking refers to a feature present in the auditory system where auditory signals are concealed due to maskers which would have just stopped, or which are about to start. The influence of masking after a strong sound (post-masking) can retain its effect for up to 200ms. However, when a sound is masked due to a masker which appears after it (pre-masking), the effect is relatively short, lasting up to 20ms (Lincoln, 1998).

Measures of auditory temporal integration have been researched for some time now (e.g. Loveless, Levänen, Jousmäki, Sams, & Hari, 1996; Sussman, Winkler, Ritter, Alho, & Näätänen, 1999; Mustovic et al., 2003; Fox, Anderson, Reid, Smith & Bishop, 2010). Much of the research related to temporal integration seems to use electrophysiological measures of assessment (Bellis, 2003). For example, Fox et al. (2010) make use of these measures to examine the development of auditory temporal integration and inhibition in children and adults. This is done by analysing the electrophysiological responses to pairs of tones, each separated by inter-stimulus intervals (ISIs) ranging between 25 and 800ms. Their results indicate that adults are better able to integrate sequential auditory stimuli into smaller temporal fragments when compared to children, suggesting that there is an obvious maturational development between childhood and adulthood in the perceptual processes supporting the assembling of incoming auditory sensory input. Clunies-Ross, Brydges, Nguyen, and Fox (2015) used event-related potentials to investigate hemispheric asymmetries using short and long temporal integration windows. The authors find symmetrical temporal

integration windows between the right and left hemispheres of the primary auditory areas. This contrasts with the secondary auditory areas where an asymmetrical temporal integration window is evident.

Despite the available research on temporal integration and masking, to the researcher's knowledge there are currently no universally approved standard tests available to measure these paradigms (Shinn, Chermak & Musiek, 2009), although clinically feasible paradigms are being investigated (Filippini & Schochat, 2014; Moore, Cowan, Riley, Edmonson- Jones & Ferguson, 2013). In addition, the equipment used in the assessment of temporal auditory integration is relatively expensive and not readily commercially available in local audiology clinics (Bellis, 2003). This results in practical clinical evaluation of temporal processing making use of assessment through temporal resolution and ordering.

2.7.2.2 Temporal ordering / sequencing. Auditory temporal ordering is the ability of an individual to accurately perceive multiple auditory signals in their precise order of presentation (Pineiro & Musiek, 1985). It is generally presumed to be crucial for the effective processing of complex stimuli such as speech recognition (Fitzgibbons & Gordon-Salant, 1996). For example, the temporal order of the spectral components in sound stimuli occurring close to each other could provide the necessary cues in the discrimination of speech sounds (Tallal et al., 1998), so that deficits in temporal order processing could cause difficulties in discriminating speech sound patterns segmenting sound sequences into individual phonemic units (Chermak & Musiek, 1997). Auditory temporal ordering is typically measured through temporal pattern sequencing tests. In comparison with the detection of auditory stimuli, these tests are considered to be more complex as they examine the processes of pattern discrimination, temporal ordering and linguistic labelling (Bellis, 2003).

Early research proposes that both temporal lobes are involved in auditory processing functions. Musiek, Pinheiro and Wilson (1980) suggest that the left temporal lobe is involved with sequential ordering of auditory stimuli, while the right is used for temporal pattern recognition. The authors further state that the perception and linguistic labelling of temporal order occurs through the interaction between temporal lobes. The extent of activation in different areas of the brain has been substantially investigated over the following years. Zatorre and Belin (2001) report bilateral responses to both temporal and spectral changes in acoustic stimuli. Temporal changes activate areas in the primary auditory cortex, while spectral effects emerge in the anterior temporal lobes. This result is consistent with a previous study revealing the importance of the right temporal area in the perception of changes in pitch (Johnsrude, Penhune, & Zatorre, 2000). It has, in turn, been suggested that verbal sequencing of sounds requires the perception of pitch patterns in the right hemisphere, the transmitting of sound across the corpus callosum, and the processing of patterns for linguistic labelling in the left hemisphere (Bellis, 2003).

Two commonly used clinical tests of auditory temporal processing are the Frequency Patterns Test (FPT) and the Duration Patterns Test (DPT) (1994). These tests have also been used in numerous research studies on auditory temporal processing over the years, to gather trends or normative data on populations (Gordon-Saland & Fitzgibbons, 1999; Neijenhuis, Snik, Priester, van Kordenoordt & van den Broek, 2002) as well as for comparative purposes between groups (Balzan & Tabone, 2017; Tabone et al., 2016). The inclusion of these tests in the assessment battery of auditory processing for Maltese children would therefore provide an increased opportunity to compare, contrast and discuss outcomes between populations.

2.7.2.3 ***Temporal resolution.*** The term ‘temporal resolution’ is used to refer to the potential of the auditory system to react to quick changes in auditory stimuli (Shinn,

Chermak & Musiek, 2009). It describes the capability of an individual to detect and determine variations in, and between duration of acoustic signals (Samelli & Schochat, 2008; John, Hall & Kreisman, 2012), and used to examine the least time with which one can separate acoustic signals (Irwin, Ball, Kay, Stillman & Rosser, 1985; Shinn, 2003).

These skills are very important with regard to the processing of speech signals. A relation has been found between gap detection and speech perception with the explanation that speech signals include rapid intensity variations and brief silent gaps, which in turn function as phonetic cues (John, Hall & Kreisman, 2012). These temporal characteristics found in speech allow individuals to grasp perceptual cues within phonemes, words and sentences, and in turn process the timing differences present in phoneme transitions, and changes in voice and prosody (Rosen, 1992; Schneider & Pichora-Fuller, 2001). An example of this is the manifestation of the stop consonant phoneme /t/ in the word “still”, the /t/ phoneme would function as a silent gap cue in which the air stream is momentarily blocked completely and then followed by a release of air. This is opposed to the word “sill” which does not contain any gap. Another example can be related to voice onset time which leads to the perceptual distinction of the phonemes /b/ and /p/ in the syllables /ba/ and /pa/, where the perceptual boundary between the two is located at a voice onset time of 35ms (Eggermont, 2000). There has also been extensive research examining the association between temporal processing skills and the processing of degraded or distorted speech, with a number of studies finding a link between them (Pichora-Fuller, Schneider, MacDonald, Pass & Brown, 2007; Schneider & Pichora-Fuller, 2001; Snell, Mapes, Hickman & Frisina, 2002). Studies have revealed positive correlations between gap detection ability in the presence of noise or tones with speech identification in noise (Snell et al., 2002; Tyler, Summerfield, Wood, & Fernandes, 1982) and reverberation (Gordon-Salant & Fitzgibbons, 1993).

Temporal resolution has been acknowledged as part of an assessment battery for auditory processing across audiological associations (BSA, 2011; ASHA, 2005; AAA, 2011). Several approaches to temporal resolution are available (modulation detection and perception of compressed or interrupted speech). However, a commonly used practical assessment of temporal resolution is the behavioural measurement of ‘gap detection’. The gap detection paradigm mainly includes two forms, categorised by whether the signals preceding and following a silent interval are the same in terms of frequency and intensity (within channel [WC]) or different (between channel [BC]). WC stimuli have been found to result in the smallest gap detection thresholds (Grose, Hall, Buss & Hatch, 2001; Lister, Maxfield & Pitt, 2007; Mulle, 2012). A disadvantage to this stimulus is that it tends not to simulate real-life listening situations (Mulle, 2012). In order to mimic speech variations, a temporal resolution test must utilise signals that differ before and after the silent interval (de la Rosa, Heinrich & Schneider, 2004). BC testing incorporates such differences in speech, and might better characterise the resolution and acuity salient to speech recognition (Phillips, Comeau & Andrus, 2010). Nevertheless, greater inter-subject variability has been found in BC stimuli (Grose et al., 2001; Phillips & Smith, 2004; Lister et al., 2007) when compared to WC stimuli.

Gap detection assessments are relatively simple to administer (Florentine, Buus, & Geng, 1999; Wiegrebe & Krumbholz, 1999). They assess a person’s ability to detect the presence of a brief period of silence or gap within a tone or noise interval (John et al., 2012). Their aim is to establish the smallest interval detected by an individual, i.e. the gap detection threshold (GDT). GDTs differ depending on stimuli used, such as the frequency of the marker (Shailer & Moore, 1983), the spectral similarity between the markers (Phillips & Hall, 2002; Oxenham, 2000), the bandwidth of the marker (Eddins, Hall & Grose, 1992), the duration of the marker (He, Horwitz, Dubno & Mills, 1999), and whether the stimuli are

presented in a monotic, diotic, or dichotic manner (Lister & Roberts, 2005). Despite the variation of tools available to test for gap detection, most tend to be rather time consuming and not readily available in audiology clinics (Samelli & Schochat, 2008). One available clinical tool for assessing gap detection is the 'gaps-in-noise' (GIN) test (Musiek, 2003). This relatively quick assessment of temporal resolution has demonstrated to be a valuable tool, providing low variability when measuring gap detection thresholds (Samelli & Schochat, 2008).

Previous studies indicate that the GIN test is a practical WC clinical procedure of temporal resolution in both paediatric and adult populations. In contrast to other gap detection tests, the GIN makes use of broadband (white) noise rather than tonal or click stimuli (Shinn et al., 2009). Broadband noise is thought to be less sensitive to atypical hearing sensitivity at specific frequencies, and thus allows for a gap detection assessment across a wide spectrum of hearing loss configurations (John et al., 2012). A study conducted by Musiek et al. (2005) has shown that for 50 normal hearing adults ranging from 13 to 46 in age, mean GDT derived for the GIN was 4.9ms and 4.8ms in the right and left ears. On the contrary, in 18 adults with CANS dysfunction, aged between 20 and 65 years, the mean GDTs were 8.5ms and 7.8ms in the right and left ears. Musiek et al. (2005) report a sensitivity of 67% and specificity of 94% in this study. Samelli and Schochat (2008) find similar results in normal hearing young adults, exposing a mean GDT of 4.19ms when assessed using the GIN test. The GIN is later administered to six groups of typically developing children aged between 7 and 18 years (Shinn et al., 2009). While no development effect is observed in the GDTs of the six groups, it emerges that temporal resolution develops relatively early and symmetrically, and children as young as 7 years perform similarly to normally hearing adults.

Reliability and validity studies of temporal resolution. A number of studies have looked at the GIN performance in normal populations ranging from children to adults.

Musiek et al, (2005) carry out the GIN on 50 normal-hearing listeners ranging between 13 and 46 years. They find gap detection thresholds of 4.8 msec in the left ear and 4.9 msec in the right, with a percentage correct of 70.2% and 70.3% respectively. In this study, subjects were asked to press a button when they heard the gap. Reliability testing for the GIN is carried out using the test-retest method on 10 individuals aged between 22 and 40 years. Overall, no difference in performance is found between the two test administrations, with Pearson product-moment correlations for both the right and left ears confirming test-retest reliability ($r = 0.95$ and 0.88 , $p \leq 0.01$) (Musiek et al., 2005). In addition, some studies (Musiek et al, 2005; Samelli & Schochat, 2008) have calculated inter-list comparisons between the four tracks of the GIN test in order to detect any substantial differences in the average GDTs and TPC answers of each list. The outcomes show no statistically significant differences across the lists, resulting in a good inter-list equivalency and internal consistency of the tool.

Musiek et al's (2005) study goes on to examine the clinical validity of the GIN. Specifically, they are interested in finding out whether the tool was sensitive to neurological pathology of the central auditory nervous system (CANS) through assessing subjects with neurological lesions of the CANS. The GDTs of these subjects show a statistically significant difference, averaging at 7.8 and 8.5 msec in the left and right ears. The authors conclude that this indicates the GIN to be a clinically useful tool in the assessment of temporal processing. Later studies have further examined the ability of the GIN to detect neurological lesions of the CANS. More recently Batista, Lemos, Rodrigues and de Rezende (2014) have used the GIN to examine whether it can be used to detect temporal processing deficits in patients with neurofibromatosis type 1 (NF1), a genetic disease which affects synaptic plasticity, memory and learning (Johnston, 2004). The authors find a deficit in temporal resolution in all subjects with NF1, in which the difference in the GDT thresholds

were statistically significant. They conclude that the neurofibromin deficiency in the subjects with NF1 could reduce the effective synaptic connections, causing the difficulties in temporal resolution (Johnston, 2003).

Researchers have also looked at the ability of the tool to differentiate between children diagnosed with literacy deficits and typically developing children. Zaidan and Baran (2013) assessed 61 children aged between 8;01 and 9;11 years; 31 of which were diagnosed with dyslexia. The results obtained show longer GDTs in the children with dyslexia (8.5 msec in the right and 8;0 msec in the left), when compared with their control group (4.2 and 4.3 msec in the right and left ears respectively). This result is significantly different for the two groups. (Mann-Whitney; $p < 0.001$). A similar study carried out by Chaubet, Perreira and Perez (2014) on 26 children aged 10 to 15 years obtains similar results to Zaidan and Baran (2013). This study subdivided groups as diagnosed with dyslexia and with specific reading and writing disorder. Their results were of 7.1 (and 55.6% correct score) and 7.2 msec (and 55.6% correct score) for the former group, with 7.8 (and 57.44% correct score) and 7.4 msec (and 60.67% correct score) in the latter, for the right and left ears respectively. There is no significant difference between the two groups ($p > 0.05$). However, this contrasts with the control group who obtained scores of 4.6 (73.33%) and 5.0 msec (72.65%) in the right and left ears. These findings suggest that the tool might be clinically valid to differentiate children with literacy difficulties from their TD counterparts.

2.7.3 Monaural low redundancy speech tests. The acoustic properties of speech are made up of complex structures incorporating numerous constantly changing frequencies over a time-interval; some very rapidly, as in the case of onset bursts, and others not so rapidly, such as vowel segments (King, Warrier, Hayes, & Kraus, 2002). The timing cues that bring about segregation within the auditory stream, and in turn, speech perception are

brought about through neural synchrony in the brainstem (Akhoun et al., 2008, Tzounopoulos & Kraus, 2009).

Verbal communication in everyday situations often results in speech sounds being degraded, commonly due to presence of interfering background noise (Wong, Uppunda, Parrish, & Dhar, 2008) making it challenging to the listener. Researchers have investigated different aspects considered salient to the processing of speech in noise. Research has established that neural synchrony is degraded in noise, resulting in differences in brainstem (Burkard and Sims, 2002; Russo Nicol, Musacchia & Kraus, 2004) and cortical (Billings, Tremblay Stecker & Tolin 2009) auditory evoked responses. This causes a disruption in how that temporal aspects of the stimuli are represented (Anderson, Skoe, Chandrasekaran, & Kraus, 2010). Peters, Moore, & Baer (1998) found that in order to understand this degraded speech, individuals tend to make use of the temporal and spectral variations between the target sound and background noise.

Studies also suggest that higher order processing including working memory (Rudner, Rönnerberg & Lunner, 2011) and attention (Ferguson et al., 2011) are the factor underlying the skill of listening in noise. An imaging study by Wong et al. (2008) revealed increased brain activation in the auditory cortex (within the frontal, parietal and temporal regions). The authors attribute this to the sensory processes involving the central nervous system, combined with higher level cognitive and attentional processes, and augment their conclusions by reporting previous imaging findings (Lipschut, Kolinsky, Damhaut, Wilker & Goldman, 2002; Pugh et al., 1996) who find activation in the same regions of the brain during auditory attention tasks.

Monaural low redundancy tests provide monaural sound stimuli which are degraded in terms of frequency, temporal, or intensity (Krishnamurti, 2007). These types of tests are one of the most commonly used assessments of auditory processing (Chermak, Traynham,

Seikel, & Musiek, 1998). Redundancy is important for the auditory processing function. It comprises both intrinsic and extrinsic redundancy, where the former refers to the way the auditory pathways convey the auditory information along the CANS (Hall & Mueller, 1997). The latter, on the other hand, stems from various interrelating acoustic (e.g. frequency, timing and intensity) and linguistic (e.g. phonology, syntax, morphology and prosody) stimuli which are present in the speech signal (Sanders & Goodrich, 1971). Extrinsic redundancy can be altered through low-redundancy speech materials, in that low-redundancy stimuli such as nonsense words would be much less intelligible than high-redundancy material such as sentences and digits (Krishnamurti, 2007). In fact, an early study (Miller, Heise, & Lichten, 1951) analysing the speech intelligibility of sentences, digits and nonsense words in individuals with normal hearing levels found that the subjects were able to obtain a 100% correct response score when repeating digits at a signal-to-noise (SNR) ratio of -10 dB, but could only obtain a 70% correct response score when repeating nonsense words at a SNR of 18 dB. The rationale behind decreasing the extrinsic redundancy is to examine the performance of individuals who might also have a reduced intrinsic redundancy. An individual with normal intrinsic redundancy would still perform normally when the extrinsic redundancy is reduced. Contrastingly, a person with a reduced intrinsic redundancy would result in a performance breakdown when presented with stimuli of reduced extrinsic redundancy (Krishnamurti, 2007).

The most common methods of reducing the extrinsic redundancy are by changing the frequency or temporal characteristics of the speech signal, or by adding background noise to the speech signal. Speech-in-noise tests require the listener to recognise the intended speech signal from background noise. This skill demands the encoding of both frequency and temporal information in the brainstem, together with auditory attention and working memory

processes (Anderson et al., 2010), which is important in extracting the signal from the noise in order to facilitate speech understanding (DeBonis, 2015).

In order to successfully process speech, listeners must acquire and develop sensory, cognitive, and neural resources for managing noise (Wong et al., 2008).

This study incorporated the development of a new assessment of speech perception in noise. This was necessary due to the language situation in Malta. Most commercially available assessments of monaural low redundancy use American or British English as the presented speech stimuli, with limited published data on their sensitivity and specificity to lesions of the CANS and paediatric populations with APD (Krishnamurti, 2007). While considering that the languages spoken in Malta are both Maltese and English the researcher opted to construct two sets of nonsense words (one based on Maltese phonotactic rules, while the other based on English phonotactic rules), with an added background multi-speaker babble at a SNR of between 5 and 8.

2.8 Development of auditory processing skills with age in children

The time needed for auditory maturation to occur has been documented in the literature, where two divergent models have surfaced (Bishop, Anderson, Reid, & Fox, 2011). The stability model proposes that the central auditory system is mature by middle childhood. This model has been supported through studies showing that temporal processing skills as well as auditory signal detection reach maturity by 9 years of age (Mattock, Amitay & Moore, 2010; Moore et al., 2010). A neuroimaging study (Devous et al., 2006) also supports this model, reporting that the primary auditory area is stable by the time a child is 7 years old. Nevertheless, the same authors also report continuing changes in the secondary auditory cortex throughout adolescence, falling in line with the incremental model proposal: i.e. that auditory function develops progressively until adulthood (Bishop et al., 2011). The

incremental model has been supported by various studies incorporating behavioural and electrophysiological methods. In a study investigating the development of temporal, spectral and binaural processing skills, Moore et al. (2011) demonstrated that children matured at different rates within and across tests. The authors suggest that the processing of different auditory stimuli takes place through separate mechanisms. Similar outcomes are reported by Dawes and Bishop (2008), with fine temporal processing demonstrating maturity by age 6, and the other temporal processing skills showing age-related improvements, with the evident emergence of individual performance differences within the tests. Other studies have investigated the perception abilities of speech in noise with age. Eisenburg et al.'s (2000) study demonstrates that younger children (aged 5 to 7 years) have lower speech in noise perception abilities than older children (aged 10 to 12 years) when using sentences, words and nonsense syllables. Comparable findings are reported in a later study by Talarico et al., (2007), with the youngest group (aged 6;0 to 8;7 years) demonstrating the weakest speech in noise abilities compared with the older groups. What these studies do not show is whether there is a difference in performance within the groups (for example, did the group of 7 year-olds perform better than the 6 year-olds?). Moncreiff and Wilson (2009) show an improved performance with age across individuals aged between 10 and 28 years (especially in the left ear) in various dichotic digit tasks, resulting in smaller interaural asymmetries among the adult participants. Moncreiff (2011) further report differences in dichotic listening between younger and older children, evident though larger ear advantages (between ears) in the younger children. The author attributes this to immaturities in dichotic listening skills as well as poorer attention and verbal memory in the younger children, resulting in higher variability in performance. With documented strong correlations between auditory memory and dichotic listening tasks (Stavrinos, Iliadou, Edwards, Sirimanna, and Bamiou, 2018), it is perhaps not

surprising that the younger children exhibiting weaker executive function skills would also have poorer dichotic listening skills.

Studies investigating auditory development through event-related potentials (ERP) also report changes in auditory ERP with increasing age between childhood, through to adolescence and adulthood (e.g. Albrecht, von Suchodoletz, & Uwer, 2000; Ponton, Eggermont, Kwong & Don, 2000; Sharma, Kraus, McGee & Nicol, 1997). Yet their results do not establish a substantial difference between the waveforms of children aged 7 to 11 years (Bishop et al., 2011). Investigations by Bishop, Hardiman, Uwer and von Suchodoletz (2007) lead to the finding that auditory ERP might change in a step-wise manner rather than a consistent gradual change. More recently, Bishop et al. (2011) have demonstrated maturational changes in the auditory ERP within this age group, measured from the fronto-central areas of the brain. On the other hand, the authors also document little developmental change in the ERP recorded from the temporal area. They argue that the development and maturation of the auditory system cannot be looked at as a single process, suggesting application of both stability and incremental models.

With research studies indicating varied stages of maturational patterns across different AP skills in the paediatric population, it was of interest to shed light on this development in Maltese children and add on to the already extensive literature across populations.

2.9 Auditory processing skills in relation to gender

Structural and functional differences in the brains of male and female individuals have been frequently reported in research utilising brain imaging (Cosgrove, Mazure & Staley, 2007; Ingalhalikar, 2014) and electrophysiological methods (Bilger, Matthies, Hammel &

Demorest, 1990; Jerger & Hall, 1980; Lamprecht-Dinnesen et al., 1998) with gender differences reported in the auditory processing of speech sounds (Krizman, Skoe & Kraus, 2012), language (Burman, Bitan & Booth, 2008; Jaeger, Lockwood & Valin, 1998; Phillips, Lowe, Lurito, Dzemidzic, & Matthews, 2001; Shaywitz, Shaywitz, Pugh, & Constable, 1995), as well as music (Koelsch et al., 2003a; Koelsch, Maess, Grossmann & Friederici, 2003b).

Research by Bilger et al. (1980) and the more recent Lamprecht-Dinnesen et al. (1998) on frequency resolution exhibited by the efferent auditory system through spontaneous otoacoustic emissions (SOAEs) disclose a greater amount and larger emissions in females. Larger amplitude emissions have also been reported in transient evoked and distortion product OAEs (McFadden, Martin, Stagner & Maloney, 2009). Differences between genders have also been reported in subcortical processing of phase-locked responses to speech sound characteristics (Chandrasekran & Kraus, 2010). Early research using click-evoked auditory brainstem response (ABR), a primarily high frequency stimulus (Eggermont and Don, 1980), shows females to have earlier response peak latencies than males (Jerger & Hall, 1980). No gender differences emerge when low frequency stimuli are presented (Hoormann, Falkenstein, Hohnsbein & Blanke, 1992). This finding has recently been further investigated by Krizman et al. (2012) using speech-evoked brainstem response. Their results are consistent with the previous studies, reporting gender differences in the rapidly changing speech stimuli.

Brain imaging studies have also found differences in the way male and female cortices process sounds (Krizman et al., 2012) both in terms of non-linguistic acoustic stimuli, such as music (Koelsch et al., 2003a,b) as well as linguistic stimuli, found in verbal language (Burman et al., 2008; Jaeger et al., 1998; Phillips et al., 2001) and phonological processing (Shaywitz et al., 1995)

Gender differences in auditory processing have also been investigated through behavioural measures. Studies investigating dichotic listening across gender have described different outcomes. While some early studies report no gender differences (Hiscock & MacKay, 1985), others reveal a significant right ear advantage (REA) in males but not in females (Kimura & Harshman, 1983; Lake & Bryden, 1976). Other studies find a REA in both genders (Andersson & Hugdahl, 1987; Schwartz & Tallal, 1980), with some reports that females produce more accurate responses from the left ear (Moulden & Persinger, 2000). Hirnstein, Westerhausen, Korsnes, and Hugdahl (2013) record adult performance on a dichotic listening task while obtaining simultaneous functional imaging data. Their results reveal a significant gender by age effect, in which female adolescents (but not children and adults) exhibit a stronger right ear advantage (REA). No gender differences emerge in the fMRI data.

Temporal processing across gender has been investigated in some studies, both international and local. Many studies find no statistically significant differences: Hales (2016) looks into the temporal ordering and resolution skills in Maltese children aged between 7;00 and 9;11 years and finds no statistically significant differences between genders, although the author does point out slightly better frequency discrimination scores in the female group. Cassar (2014) also investigates temporal processing skills in the Maltese paediatric population of the same age, but concentrates specifically on temporal resolution skills. Her study similarly reveals no statistically significant differences between males and females, with marginally better performance from the male group. The results of these local studies are comparable with studies on other populations. Amaral and Colella-Santos's (2010) study shows a slightly better performance by the males in temporal resolution. This reaches statistical significance when analysed in terms of 'percentage correct'. Nevertheless, the authors argue that this difference cannot be considered clinically significant. A slightly

better performance in males is also reported by Samelli and Schochat (2008) with statistical significance emerging in some subtests of temporal resolution. Other studies expose no statistically significant differences between genders in tests of temporal resolution (Wong & McPherson, 2015) as well as temporal ordering (Schochat & Musiek, 2006).

Finally, the perception of speech in noise by males and females has been examined through some studies establishing normative data and standardisation on populations (Domitz & Schow, 2000; Keith, 2000). These studies expose similar performances by males and females in this task.

This section has demonstrated differences across research studies in terms of gender effects on AP. These differences could be attributed to methodological variations as well as disparities in the sample populations investigated across studies. This research aims to add on to the existing body of research in exploring the effect of gender on a behavioural assessment battery of AP in the Maltese paediatric population. Gender differences could imply modifications in assessment interpretation and possibly follow-up intervention strategies.

2.10 Auditory processing skills in bilingual children

With reports that close to 50% of the world population is bilingual (Ansaldo, Marcotte, Scherer & Raboyeau, 2008; Grosjean, 2010), over the last three decades research has been dedicated to investigating the processing of stimuli in bilingual populations. This section provides review on the performance of monolingual and bilingual speakers across tests of auditory processing. One is to keep in mind the heterogeneity of bilingual populations. Studies report outcomes in specific bilingual populations. Thus, what might emerge from one bilingual population may not necessary occur across different bilingual contexts.

Comparisons between monolingual and bilingual individuals have pointed to advantages for the latter in terms of cognition and executive function (e.g. Bialystok, Craik, Green & Gollan, 2009; Carlson & Meltzoff, 2008; Soveri, Laine, Hämäläinen, & Hugdahl, 2011), working memory and attention control (e.g. Bialystok, Craik, & Luk, 2008; Kramer & Mota, 2015; Soveri et al., 2011), and neural processing (Krizman, Skoe, Marian & Kraus, 2014; Krizman, Slater, Skoe, Marian, & Kraus, 2015).

Divided attention and working memory has frequently been investigated through dichotic listening tasks (Conway, Cowan, & Bunting, 2001; Colflesh & Conway, 2007), leading to further research comparing monolingual and bilingual individuals on this task (e.g. Soveri et al., 2011; Greesele, Garcia, Torres, Santos, & Costa, 2013; Onoda, Pereira, & Guilherme, 2006). The studies investigating these skills in adult participants of differing language backgrounds report better performance from their bilingual groups. Filippi, Morris, Richardson and Bright (2015) report proficiencies of monolingual and bilingual children in focusing attention to a target sentence while ignoring a distractor sentence. Their results also expose better performance in the bilingual children suggesting that these children are advantaged in controlling auditory interference from a young age.

Some early studies investigate the performance of bilingual individuals on dichotic listening tasks in their primary and secondary languages. Contrasting results are described, with some reporting better performance on tasks presented in the primary language (Gordon & Zatorre, 1981) and others reporting participants performing better in one language, irrespective of the primary language (Albanèse, 1985).

The combined activation of two or more separate language systems causes increased cognitive demands on the bilingual brain, which in turn results in physical (Ressel et al., 2012) and functional (Costa & Sebastian-Galles, 2014) alterations in its neural networks

(Bidelman & Dexter, 2015). While these changes have been found as advantageous to cognition, attention control and executive functions in bilingual individuals, as was explained previously, disadvantages in other just as important functions are also evident (Bidelman & Dexter, 2015) such as smaller vocabulary in one language (Armon-Lotem & de Jong, 2015), and reduced verbal fluency (Portocarrero, Burright & Donovanick, 2007). In fact, counter to their dichotic listening skills, bilingual individuals tend to perform worse than monolinguals on speech-in-noise tests (e.g. Krizman, Bradlow, Lam & Kraus, 2016; Mayo, Florentine & Buus, 1997; Rogers et al., 2006; Tabri, Smith Abou Chacra, & Pring, 2010). Speech used in conversation incorporates variability and ambiguity. In turn, its perception requires precise sensory processing together with higher order processing in order to match the speech signal with its corresponding phonological, lexical and semantic representations (Lecumberri, Cooke & Cutler, 2010). While bilingual individuals are able to perform at par with their monolingual counterparts in perceiving speech in quiet, their ability to process speech signals in the presence of noise poses a greater challenge to them (e.g. Rogers et al., 2006; Shi, 2010; Tabri et al., 2010). Bilingual speakers have been found to perform better with speech perception in noise presented in their primary native language, possibly due to the increased knowledge and practice of linguistic factors in their primary language (Golestani et al., 2009). Lecumberri et al., (2010) support this claim, suggesting that the decreased phonotactic and semantic knowledge in the second language could have adverse effects on the understanding of speech in noise. The age of second language acquisition also seems to affect the performance of this skill, with late bilinguals being found to perform worse than early bilinguals when tested in their second language (Mayo et al., 1997).

As has been discussed in section 2.4.2, auditory temporal processing is considered important for speech perception, possibly forming a base for the auditory processing of rhythm, sound duration and pitch differences, as well as differentiation between different

phonemes (Frederigue-Lopes, Bevilacqua, Sameshima, & Costa, 2010). Some studies have looked into the effect of bilingualism on auditory temporal processing tests using non-linguistic auditory stimuli (e.g. Onoda, 2006; Sanayi et al., 2013). These studies, which investigated languages that were entirely different from each other, reported contrasting results. While Sanayi et al. (2013) find no differences in the temporal processing of Persian monolinguals and Azeri-Persian bilinguals, Onoda et al. (2006) report a better performance in the pitch perception of bilingual Portuguese-Japanese bilinguals when compared with monolinguals speaking Portuguese. Similar to the latter study, Oppitz et al. (2014) find Spanish-English bilinguals to perform better than monolinguals on tests of temporal ordering.

Auditory temporal processing in bilingual individuals has also been researched using time compressed speech. A recent study investigating the effect of temporal processing on speech recognition in a similar population as the Sanayi et al. study, i.e. Azeri-Persian bilinguals and Persian monolinguals (Rahmani, Jarollahi, Hosseini, Soleymani, 2015), reports similar results to bilingual studies investigating speech in noise and contrasting results to Sanayi et al. The researchers find that speech recognition in the bilingual group is lower than the monolingual group when a compression rate of 40 percent is used, with the difference becoming more significant with increasing compression rate. This might suggest that the auditory temporal processing abilities differ depending on the sound stimuli used. It cannot be ignored, however, that the speech test in Rahmani et al.'s (2015) study is administered in the participants' second language. Thus, although they are reported to be early sequential bilinguals, their language background might have also had an effect on the study result outcomes. One might also expect a poorer performance in bilinguals due to the increased cortical involvement required in processing sounds in the harder listening conditions (Shi & Farooq, 2012). The use of both lexicons evident in bilinguals (as opposed to a single lexicon in monolinguals) might also explain the difference in performance between the two groups

(von Hapsburg & Peña, 2002). Rahmani et al. (2015) suggest that bilingual individuals need more time to process words in their active languages, so that if listening conditions are made more complex through an increase in the speech compression rate their performance would be poorer than their monolingual counterparts.

Within the Maltese linguistic and cultural context it is rather rare for a child to be brought up as a monolingual speaker. There tends to be a variety in the bilingual distribution, with most individuals using Maltese as a primary language (PL) (Grech & Dodd, 2008). Nevertheless, with the small, yet significant proportion of PL English speakers, this variety should not be ignored. The language context unique to the Maltese warrants the need to study the specific performance of this population in AP behavioural tests.

2.11 Auditory processing skills in relation to the geographical regions in Malta and school type: Implications for socioeconomic status

The Maltese islands were originally divided into three regions as created by the Local Councils Act of 1993 and then incorporated into the 2001 constitution: (1) The North Western region (*Malta Majjistral*) was made up of three statistical districts: the Northern, Northern Harbour, and Western districts; (2) The South Eastern region (*Malta Xlokk*) was further divided into the South Eastern and the South Harbour districts; (3) the sister island of Gozo (Malta, 2010). These regions were later re-divided by the Act No. XVI of 2009 into five regions: (1) Central, (2) Gozo, (3) Northern, (4) South Eastern, and (5) Southern.

The schools in Malta are divided into two main categories: state and private schools. Families of children attending state schools are not charged any tuition and school transport fees, as well as for books and school materials. Private schools are further divided into two sub categories: church schools and independent schools. Church schools in Malta generally belong to the Catholic Church (Education, 2015).

Various studies have linked socioeconomic status (SES) to geographical regions (Gatt's (2012) study on the Maltese situation) and school types (e.g. Perry & McConney, 2010; PISA, 2011; PISA, 2016). Gatt (2012) reveals a strong North-South divide across Malta, with the Northern part being subjected to less socio-economic inequalities and better general conditions (lower unemployment rates, less poverty risk and higher income), as opposed to the Southern Harbour district, which is found to encompass the highest rates of socio-economic inequalities in Malta.

Research investigating SES across schools has shown that students and schools of a disadvantaged SES display a poorer academic performance in comparison with their more advantaged peers (Perry & McConney, 2010). The PISA (2011) report, which deals with 16 OECD countries (countries who are members of the Organisation for Economic Co-operation and Development) and 10 partner countries¹¹, discloses that the students who attend private schools perform significantly better in academic assessments than those who attend public schools. Nevertheless, the report also states that students in public schools coming from a similar socio-economic context as private schools tend to do equally well (PISA in focus, 2011). This could imply that there might be more children of a higher SES attending private schools.

The relation of SES with neurocognitive functions of language, memory and executive functioning has revealed discrepancies between the neural structure and functioning in children of different SES environments (Noble, Houston, Kan & Sowell, 2012; Ursache & Noble, 2016). Studies show that children from poorer SES backgrounds are subjected to less cognitive and linguistic stimuli (Cartmill et al., 2013) and as a result present with weaker skills in language and cognition (Ursache & Noble, 2016). SES has also been found to effect auditory processing skills (APS). Children of a poorer SES have been

¹¹ Malta was not included in this study.

observed to exhibit more difficulty in general APS in comparison with children of a higher SES, influencing the acquisition of early vocabulary and receptive language processing speed (Kraus & Anderson, 2015). These children are often subjected to noisier settings (Kohlhuber, Mielck, Weiland, & Bolte, 2006). Electrophysiological studies reveal that children of poorer SES are less able to suppress irrelevant auditory input when carrying out tasks of active listening (auditory selective attention (ASA)) (e.g. D'Angiulli, Herdman, Stapells, & Hertzman 2008a; D'Angiulli, Weinberg, Grunau, Hertzman, & Grebenkov, 2008b; D'Angiulli et al., 2012; Jones, Moore & Amitay, 2015; Stevens, Lauinger & Neville, 2009). Findings from these studies show a significant difference in the event related potential (ERP) waveforms of attended and unattended auditory stimuli in children coming from a high SES, but no significant differences in children of low SES. The automatic processing of sound in individuals coming from a low SES backgrounds can also be affected, in which weaker and noisier neural responses to signals of speech have been reported (Skoe, Krizman & Kraus, 2013). The opposite is found in children coming of a high SES, where stronger attentional skills emerged (Ison, Greco, Korzeniowski, & Morelato, 2015). The impact of SES on comprehending speech in a noisy background is a topic attracting much investigation. SES effects on the recognition of speech using a sentence imitation task (SIT) in quiet and in noise reveal a similar performance in children of both low and high SES for the SIT in quiet, but differences in noise, where the group of a lower SES performed worse (Becker, Costa & Lessa, 2013). The authors attribute this to the typical noisy environments where the children of lower SES reside in, and the possible insufficient auditory stimulation. This poorer ability to perceive speech in noise might affect learning, since noisy classrooms are very common. Auditory processing in children of varying SES environments has also been investigated for temporal processing (TP) abilities (Balen, Boeno & Liebel, 2010; Maamor, 2010). These studies found the poorer TP skills to be more commonly present in regions of low SES.

2.12 Comorbidity of APD

Numerous research studies have been carried out with the general aim of establishing what APD is, in terms of its diagnostic markers, mode of assessment and further management (Ferguson, Hall, Riley, & Moore, 2011). However, no general consensus has been reached as yet (Ferguson et al., 2011; Rosen, 2005). Audiological societies and special interest groups, such as ASHA (2005) and the BSA (2011b) have defined APD as a deficit in the neural processing of auditory stimuli resulting in poor perception of both speech and non-speech sounds. This deficit in the auditory system could include both afferent and efferent pathways, as well as a combination of both 'bottom-up' (sensory driven) and 'top-down' (concept driven) processes. Nevertheless, these associations hold that although APD may co-occur with other higher-order difficulties, such as impairments of language, attention deficit hyperactivity disorder (ADHD), reading difficulties, Autism Spectrum Disorders (ASD) (ASHA, 2005; BSA, 2011a,b), as well as lower intelligence (Jerger & Musiek, 2000), it is not the result of these difficulties. Similarly, these difficulties are not the result of the APD (ASHA, 2005).

APD incorporates a number of symptoms, as have been reported in the literature. It is commonly reported that despite normal peripheral hearing, individuals with APD seem to have difficulties similar to those with hearing difficulties (Stollman, 2003), such as finding it difficult to understand in the presence of background noise, not able to adequately follow oral instructions, and difficulty understanding fast or degraded speech (ASHA, 2005; Jerger & Musiek, 2000). There are symptoms that tend to overlap with other developmental disorders. One of these symptoms is poor attention and distractibility (ASHA, 2005; BSA, 2011b; Jerger & Musiek, 2000; Riccio, Cohen, Garrison, & Smith, 2005; Witton, 2010) – a symptom which is also dominant in children with ADHD according to the diagnostic manuals by the

WHO (ICD-10) and the American Psychiatric Association (DSM-V). Another reported characteristic is that of language and/or communication difficulties (ASHA, 2005; BSA, 2011; Ferguson et al., 2011; Sharma et al., 2009). The overlap with reading difficulties has also been documented (Cantiani, Lorusso, Valnegri, & Molteni, 2010; Dawes & Bishop, 2009). Finally, various research studies have documented difficulties of auditory processing in children with Autism Spectrum Disorder (ASD) (Egelhoff, 2011; Jones et al., 2009).

In light of the above literature one could deduce that when a child is diagnosed with a developmental disorder, the chances that symptoms of other developmental disorders are present is significantly increased (Witton, 2010). This is most probably due to the extent with which different brain regions are interconnected, so that cognitive sections (language and memory) do not develop and function independently, but rather interact through complex processes (Karmiloff-Smith, 1998). Currently, the main focus of research seems to be on whether APD can occur independently of other difficulties, i.e. as a 'pure' disorder, or whether it manifests itself as a category present in other disorders. If one is interested in understanding the causal mechanism of APD with the primary intention being research focused, then it would warrant focusing on subjects presenting solely with a 'pure' disorder of APD with the intention of reducing or removing any additional difficulties which would confound the results (Dawes & Bishop, 2009). However, this population seems to be very rare (Witton, 2010), as is confirmed through a study by Sharma et al. (2009). In this study it is found that only 4% of the subjects tested could be diagnosed as having a 'pure' APD. On the other hand, for clinical purposes this direction of research may not be relevant since most of the presenting children would have the additional difficulties in hearing, language, reading, attention, and social skills (Dawes & Bishop, 2009). The line of research looking at the clinical aspect of APD seems to be more concerned with the relation between APD and the other disorders. There is a debate as to whether the auditory deficit is the primary cause of

the further difficulties, or a secondary consequence (Dawes & Bishop, 2009), or whether it simply co-occurs and is present alongside other disorders (BSA, 2011a,b). In the following sections the outcomes of research studies looking into the comorbidity of APD with disorders of language and literacy is presented.

2.12.1 Developmental language disorder (DLD) and literacy difficulties (LitD).

A small percentage of children (6 to 8%) have difficulties in acquiring language, despite having no neurological, psychiatric, or cognitive impairments, exhibiting no problems with vision and hearing, and being raised in adequate communicative surroundings (*American Psychiatric Association*; APA, 2013). From the early stages of language acquisition, these children are observed to fall behind typically developing children in terms of vocabulary acquisition, morpho-syntactic skills, and use of complex syntactic structures (APA, 2013; Rinker, 2006). Linked with DLD there is evidence of co-occurring literacy difficulties (LitD)¹² (Catts, Adlof, Hogan, & Weismer, 2005; McArthur, Hogben, Edwards, Heath, & Mengler, 2000; Ramus, Marshall, Rosen, & van der Lely, 2013).

The relationship between APD and difficulties of language and literacy is perhaps the most debated and discussed in the literature (Dawes & Bishop, 2009). This could be due to the fact that many children diagnosed with APD often have additional language and reading difficulties (Chermak and Musiek, 1997). One theory claims that language impairment occurs as a result of impaired auditory perception (Feldman & Messick, 2009). This was first proposed approximately 40 years ago through a study carried out by Tallal and Piercy (1973). The latter study looks specifically at temporal processing skills in children, and finds that some children with phonological difficulties have difficulties with detecting rapid temporal

¹² Literacy difficulties are referred to using various labels in the literature. Terms used are ‘dyslexia’ (e.g. Schulte-Körne et al., 1999), ‘poor readers’ (Mody et al., 1997), ‘learning disability’ (Kraus et al., 1996), ‘reading difficulties’ (Sharma et al., 2009). Throughout this section, these labels will be used interchangeably, in line with the label used in each specific study being reviewed.

changes in sounds, which in turn could result in poor literacy skills especially at the level of phonemic awareness. Other early studies support Tallal and Piercy's (1973) claim. Lubert (1981) proposes that difficulties with auditory perception underlie language impairments (as opposed to higher-order cognitive or language deficits). This conclusion is reached following results of children with a language impairment finding it difficult to perceive the order sequence of brief tones – implying a weakness in identifying acoustic characteristics of a speech wave. Following this research, Tallal published further studies analysing the connection between temporal processing and DLD (e.g. Tallal, 2000; Tallal & Stark, 1981; Tallal, Miller, & Fitch, 1993). Frumkin and Rapin (1980) had attempted to divide a group of children with a DLD into two sub-groups: one group had additional phonological difficulties, while the other group did not. Their study concludes that the children with phonological difficulties have a temporal processing deficit, while the other group does not. Other early research studies have looked at auditory perception difficulties at the level of seconds. They suggest that an impairment in the auditory perception of amplitude and pitch variation could result in difficulty perceiving prosody, which could lead to difficulties in interpreting the meaning of a spoken phrase (Bellis & Ferre 1999; Griffiths, Johnsrude, Dean, & Green, 1999). Research related to auditory temporal masking has also been investigated in children with language impairments (Wright, Lombardino, King, Puranik, Leonard, & Merzenich, 1997). The outcomes reported by Wright et al. (1997) indicate that these children are presented with temporal-masking deficits. Throughout this study, children with DLD are presented with a short tone before, during, or after a noise masker of a similar frequency. They find it difficult to detect the tone when it is presented just before the noise (known as backward masking), driving Wright et al. (1997) to suggest that children with a language impairment have difficulty with temporal-processing skills when they are required to detect a brief sound in a rapidly following auditory signal. A similar study was carried out by Zhang

and Formby (2007) examining adult subjects. The researchers question the poor performance in Wright et al.'s study, putting forward the possibility of signal-masker confusion in this paradigm rather than disordered language. They check for this by cueing all temporal stimuli with another tone presented in the contralateral ear. A significant cueing effect is measured in the backwards-masking condition but not in the other signal temporal positions, suggesting the possibility that the deficit reported by Wright et al. for children with a language impairment may be due to unwarranted signal-masker confusion, instead of a temporal-processing deficit.

More studies have been conducted with the attempt to replicate the early studies on temporal processing as an underlying cause of DLD or LitD. The results obtained have been somewhat controversial. Some studies achieve results consistent (or partially consistent) with Tallal's temporal processing hypothesis (e.g. Cantiani, Lorusso, Valnegri, & Molteni, 2010; Cohen-Mimran & Sapir, 2007; Heiervang, Stevenson, & Hugdahl, 2002). Schulte-Körne, Deimel, Bartling, and Remschmidt (1999) examine temporal processing through event-related brain potentials in children with dyslexia. They find that the children with dyslexia have a significantly smaller mismatch negativity (MMN), suggesting that they have a significant pre-attentive deficit when processing rapid temporal patterns. The authors propose that it could be the temporal information embedded in speech sounds that results in the reduced MMN rather than phonetic information. However, other studies report contrasting results. For example, Mody, Studdert-Kennedy, and Brady's (1997) analysis of the discrimination capabilities of poor readers between speech sounds and acoustically-matched non-speech sounds finds that their subjects could not differentiate between speech sounds but had no difficulty discriminating between the non-speech sounds. They conclude that the phonological deficits are related to a difficulty specifically with phonetic discrimination skills rather than auditory processing. Bishop, Carlyon, Deeks and Bishop's (1999) study

investigating the frequency discrimination in children with language impairment *does* result in poorer scores from these children (when compared to the control group). Nevertheless, the difference is not statistically significant.

Similar studies have been conducted in relation to literacy difficulties. Some studies, such as Tallal (1980) find that children with literacy difficulties are not able to sequence and discriminate between auditory signals as well as the control group when the stimuli were presented rapidly. The researcher finds a significant correlation between the ability of the children to process rapid nonverbal information and literacy skills. In a later study, Kraus et al. (1996) use electrophysiological measures to analyse children's discrimination of rapid acoustic changes present in speech. Their results show that children with a learning disability exhibit a weakness in behaviourally discriminating rapid spectro-temporal changes found in single speech syllables (such as /da/ versus /ga/). Similar to Kraus et al (1996), Sharma et al. (2006) use a combination of behavioural and electrophysiological measures to analyse the auditory processing skills in children with literacy difficulties. Their findings demonstrate that children with literacy difficulties exhibit a weakness in frequency pattern discrimination in addition to speech-syllable discrimination deficits recorded through electrophysiological measures.

More recent studies have attempted to combine temporal and phonological content. Groth, Lachmann, Riecker, Muthmann, and Steinbrink (2011) examined temporal discrimination using vowel length. The stimuli used were consonant-vowel-consonant combinations, maintaining a constant vowel but altering the temporal content (therefore use of either long or short vowels). The individuals with literacy difficulties showed poorer discrimination performance when compared to the control. The outcomes of this study suggest that developmental dyslexia is associated with impaired temporal processing.

While a number of studies have confirmed the findings of impaired temporal processing in individuals with literacy difficulties (such as Ben-Artzi, Fostick, & Babkoff, 2005; Cohen-Mimran & Sapir, 2007; Vandermosten, Boets, Luts, Poelmans, Wouters, & Ghesquière, 2011), there have also been studies that failed to observe similar findings (Breier, Fletcher, Foorman, Klaas & Gray, 2003; Bretherton & Holmes, 2003). For example, Bretherton and Holmes (2003) investigate auditory temporal processing of non-speech sounds in children with literacy difficulties using the same tone-order stimuli as that used in Tallal's (1980) study. They compare this temporal ordering skill with phonological awareness and found no relation between the two. Their results indicate that deficient temporal order judgement does not underlie difficulties in phonological awareness. Another study conducted by Watson et al. (2003) shows that temporal speech processing measures are poor predictors of reading achievement. Further reviews (Bailey & Snowling, 2002; Ramus, 2004) support the claim of this lack in correlation between the auditory processing and LI. In fact, evolving research has put forward the suggestion that while some auditory processing problems do co-occur with LitD, it is not likely that the difficulty with auditory processing is sufficient to cause the LitD (Halliday & Bishop, 2006). Therefore associations between the auditory and language /literacy impairments indicate probable common developmental substructures, rather than causality (Witton, 2010).

Dawes and Bishop (2009) suggest that an explanation for these conflicting results could be due to the heterogeneity within the population of children 'labelled' as LI (DLD) or LitD, resulting in the possibility that a sub-group could have additional or underlying difficulties with auditory perception while other sub-groups do not. The outcomes of these investigations have led researchers to look into the possibility of language impairment occurring due to impaired higher order processing rather than impaired auditory perception.

In turn, it has been proposed that higher order level processing constructs (linguistic knowledge) have an effect on auditory processing (Miller, 2011).

Galbraith, Bhuta, Choate, Kitahara, and Mullen's (1998) research emerged evidence that ABRs can be altered depending on which stimulus an individual decides to focus on. Johnson, Pennington, Lee, and Boada (2009) analyse the relationship between phonological awareness skills and performance in a rapid temporal processing task, known as backwards masking, in children with speech sound disorders. Their research shows that the phonological awareness skills at the age of five years could predict the performance of backward masking at a later stage (age eight years) more accurately than the performance of backwards masking at age five could predict the skills in phonological awareness at eight years of age. These results suggest the presence of top-down influences on auditory perception and query claims of deficits in auditory processing causing language and reading difficulties (Miller, 2011).

A recent body of research has moved into the direction of whether APD and DLD and/or LitD are linked, rather than one being a cause of the other. Different studies in the literature seem to be emerging with conflicting results on the co-morbidity between the three disorders. There has been a substantial amount of literature showing evidence that deficits in auditory processing are not necessarily related to deficits in speech, language and literacy, in that the former do not seem to cause a significant risk for later speech, language and literacy skills (Hazan, Messaoud-Galusi, Rosen, Nouwens, & Shakespeare, 2009; Ramus, White, & Frith, 2006; Rosen, 2003; Watson & Kidd, 2009). For example, Watson et al. (2003) assess the speech processing skills in the presence of difficult listening conditions on 470 children. They find that this auditory processing task is a poor predictor of academic achievement. Hazan et al. (2009) also analyses speech perception skills in children with dyslexia. They conclude that although the phonological processing skills are poor, the children's

performance on speech perception tasks is within the normal limits. McAnally, Castles and Bannister (2004) examine the performance of non-speech stimuli in children with LitD. The researchers' interest lies in finding out whether there is a link between reading skills and performance on an auditory temporal pattern discrimination test. The results show that there is no difference in the performance of delayed readers and good readers in the discrimination of high and low frequency tones. Rosen, Adlard, and van der Lely (2009) also looks at the performance of non-speech stimuli. However in this case they examined a different clinical population. The researchers analyse the performance of children with (grammatical) SLI by presenting tones both in quiet environments and the presence of background-masking noise. They find that more than half of the children perform within age-appropriate limits. Furthermore, there is a poor correlation between the non-speech-based task of auditory processing and measures of vocabulary, grammar, and phonology. The researchers conclude that the deficits in auditory processing skills that can be present in children with DLD appear unlikely to cause the disordered language.

Other studies that find co-morbidity between auditory processing, DLD and LitD. Sharma, Purdy, and Kelly (2009) assess children all suspected of having APD using a comprehensive test battery of auditory, language, reading, attention, and memory abilities. Their results show that while 72% emerged with a profile of APD, only 4% of those children were found to have 'pure' APD on the basis of the tests carried out. Nearly half of the children exhibit difficulties in all areas of auditory, language, and literacy skills, and a larger number are found to have APD co-morbid with DLD or reading difficulties (RD) rather than having APD, DLD, or RD in isolation. However, the authors do point out that due to the lack of a widely recognized "gold standard" for identifying APD, RD, and DLD, the degree of co-morbidity between these conditions does tend to vary depending on the choice of diagnostic tests. As a result, the overlap between APD, RD, and DLD is likely to differ across research

studies. Weber-Fox, Leonard, Hampton Wray, and Tomblin (2010) attempt to analyse co-morbidity between these disorders by means of electrophysiological measures. Their study uses both non-speech and speech-based materials and examines the neural activity for rapid auditory processing to these stimuli in adolescents with DLD. Their findings indicate that the auditory processing of both the tonal and language based stimuli is atypical in the DLD subjects, indicating a possible co-morbidity between APD and DLD. A number of research studies that have gathered longitudinal data in an attempt to examine whether there is in fact a link between auditory processing and language skills. Choudhury, Leppänen, Leevers, and Benasich (2007) behaviourally assess rapid auditory processing skills in babies aged 6 to 9 months with and without a family history of language impairment. They later assess their language scores at 12 and 16 months. The research reveals that the children with a family history of language impairment perform worse than the control group across all measures in the study. An earlier longitudinal study compares electrophysiological measures of temporal auditory processing in infants aged 5 months with their word production at 12 and 24 months of age (Weber, Hahne, Friedrich, & Friederici, 2005). The findings of this latter study show that reduced electrophysiological measures correlated with later lower word production.

Perhaps one way of naturally investigating the relationship between auditory processing and language and/or literacy deficits is to look into the possible co-morbidity within populations not diagnosed with these deficits. Halliday, Tuomainen and Rosen (2017) recently aimed at this by testing the AP and language skills in children and adults with a mild to moderate sensorineural loss – a population known to exhibit difficulties in AP skills. The study highlights several routes that relate auditory processing deficits to language difficulties, as opposed to a specific AP deficit leading to language and literacy difficulties, and concludes that AP deficits might (but not always) be necessary and enough to cause language difficulties.

In light of the frequently reported comorbidity between AP and language disorders, a thorough assessment of language processing is recommended in order to identify any DLD which may influence the audiological results. With the complex link and interrelationship between AP, language and cognition, assessment of the latter two through a multidisciplinary approach would investigate whether the AP results might be primarily a result of a higher-level disorder or otherwise (Iliadou et al., 2017).

2.12.2 Attention deficit-hyperactivity disorder (ADHD). ADHD is a neurodevelopmental disorder commonly present by the time a child enters primary school. It is characterised by persistent inattention and can also include hyperactivity/impulsivity, interfering with an individual's development or functioning (APA, 2013). Substantial effort has been put into examining the comorbidity of ADHD with other neurodevelopmental and psychiatric disorders (Pliszka, 2009). Research has also delved into possible psychiatric biomarkers for the disorder, despite the complexities that arise due to its heterogeneous nature (Faraone & Bonvicini, 2014). Although no single reliable ADHD biomarker has been described to date (Thome et al., 2012), some potential candidates for useful biomarkers have been proposed (the reader is referred to Faraone and Bonvicini (2014) to review further this area). However, at present children are diagnosed through presenting symptoms of six or more as specified in the DSM-V (APA, 2013), which have persisted for at least 6 months to an extent that it results in inconsistency with their developmental level, and that has a negative impact on social and academic performance.

Differentiation between ADHD and other developmental disorders can be rather challenging (Sulkes, 2013), especially during childhood where the presenting symptoms of ADHD can also occur in other developmental and psychiatric disorders (Gillberg, 2010). The reported rates of comorbidity of ADHD and other disorders range between 10% and 50%

(Buckley, Miller, Lehrer & Castle, 2009; Root & Resnick, 2003). The presenting symptoms of ADHD can be very similar to APD, where both disorders are linked with deficits in auditory attention, weak listening skills, and difficulties in academic performance (Chermak, Tucker & Seikel, 2002). In a study by Rosen, Cohen and Vaniasegaram (2010), 60% of the children suspected of having APD also report difficulties with attention and concentration. These symptom overlaps lead to difficulties in bringing out a differential diagnosis (Brown, 2009). So rather, exploring the auditory processing in children with ADHD has become of interest.

Ghanizadeh (2009) investigates screening signs of auditory processing in terms of hypo- and hypersensitivity to sounds in children and adolescents diagnosed with ADHD and with or without oppositional defiant disorder (ODD) and separation anxiety disorder (SAD). These results show that ADHD alone does not predict auditory dysfunction, but that those with co-morbid ODD are under-responsive to auditory stimuli. A local study (Tabone et al., 2016) compares the listening skills in children with ADHD to typically developing children via a questionnaire. The questions explores (1) auditory attention and memory, (2) conversation skills, (3) sensory stimulation, (4) listening in noise, and (5) social situations. The children with ADHD, as scored by their parents, perform significantly worse than the typically developing children in all situations. Tabone et al.'s study further compares the performance of the two groups on behavioural subtests of auditory processing incorporating both linguistic (Dichotic listening and speech-in-noise tests) and non-linguistic stimuli (temporal ordering of duration and frequency as well as temporal resolution tests). The authors report significant differences in all stimuli. On the other hand, few significant differences emerge in the tests of temporal processing between the groups, in which these differences are limited to only one ear. In the dichotic listening tasks, using digits, the ADHD group perform significantly worse than the controls on both ears for both free recall

(non-forced) as well as forced right and left conditions, with the weakest performance occurring in the forced left condition. Similar findings are reported in previous studies. Manassis, Tannock and Barbosa (2000) explore dichotic listening of two-syllable words in children with ADHD and ADHD plus anxiety. Amongst their results, they reveal weaker performance from their ADHD group. Dramsdahl, Westerhausen, Haavik, Hugdahl and Plessen (2011) investigate forced and non-forced dichotic listening of syllables in adults with ADHD and find them to perform weakest in the forced left condition. The authors attribute this to a cognitive control deficit when in conflict situations.

The effects of noise in individuals with attention difficulties has been investigated in the literature. The Maltese children in Tabone et al.'s (2016) study performs at par or better than the typically developing controls on the speech in noise tests using speech babble at a signal-to-noise ratio (SNR) of between +5 and +8. Consistent results also emerge in a study by Söderlund and Jobs (2016), who investigate the performance of children with attention deficit and typically developing children on a speech recognition test in noise. The authors report a better performance in the inattentive group. Some studies report noise to be beneficial to these individuals while being detrimental to controls (Söderlund, Sikström, & Smart, 2007; Söderlund, Sikström, Loftesnes & Sonuga-Barke, 2010). These studies find that their subjects with attention deficits perform better on tasks of sentence recall in background white noise at -1 SNR. They conclude that background noise can be beneficial for cognitive performance in children with attention deficits. Other studies present contrasting results, reporting children with ADHD to perform significantly poorer than the controls on the speech-in-noise tasks (Abdo, Murphy & Schochat, 2010).

Research work on ADHD theory proposes that deficits in temporal information processing could play a part in weak cognitive and behavioural outcomes. However, methods for assessing temporal skills varies and could pose difficulties to amalgamate

findings across studies (Toplak, Dockstader & Tannock, 2006). There seems to be agreement between studies that individuals with ADHD do not present with significant difficulties in frequency temporal processing. This outcome emerges both in studies on Maltese subjects (Tabone et al., 2016) as well as international studies (Abdo et al., 2010; Radonvich & Mostofsky, 2004; Toplak, Rucklidge, Hetherington, John & Tannock, 2003). Tabone et al. (2016) also do not reveal poor performance in duration processing and gap detection. A similar outcome was previously reported by West et al. (2000), where the authors observe no differences between ADHD and control groups on an auditory time reproduction task. Other studies provide contrasting results, revealing differences in duration temporal processing tasks (Radonvich & Mostofsky, 2004; Van Meel, Oosterlaan, Heslenfeld & Sergeant, 2005).

The outcomes of the studies highlighted above suggest that the variability in results across studies suggests that children diagnosed with ADHD might present with deficits in auditory processing. Performance might depend on the current attentive state of the individual, whether they are taking medication targeting the attention deficit, and the specific auditory processing skill assessed. And in turn sheds light on clinical implications for the assessment of AP skills in this population.

2.12.3 Autism Spectrum Disorders (ASD). ASD, a spectrum of neurodevelopmental disorders (O'Connor, 2011) has been defined by the DSM-V as including incessant deficits in both communication and social interaction, repetitive and restrictive behaviour patterns within different contexts. These deficits cannot be justified through a definition of general developmental delay (APA, 2013). Despite the main characteristics defining ASD, the responses to auditory stimuli have been of interest and

researched extensively, both through electrophysiological and behavioural methods (Egelhoff, 2011) and using an array of linguistic and nonlinguistic stimuli.

Research on temporal pitch processing using behavioural methods has consistently reported that individuals with ASD were better at perceiving pitch than their typically developing counterparts when presented with nonlinguistic stimuli such as pure tones and musical chords (Bonnell et al., 2003; Heaton, 2003; Heaton, 2005; O’Riordon & Passetti, 2006). Similar results have been reported in studies investigating pitch perception using linguistic stimuli, where children with ASD outperformed their typically developing counterparts in interpreting the pitch contours in sentences (Järvinen-Pasley & Heaton, 2007; Järvinen-Pasley et al., 2008), monosyllabic words and nonsense words (Heaton, Hudry, Ludlow & Hill, 2008; Heaton, Williams, Cummins & Happé, 2008).

Proposals have been put forward that the ‘non-speech preference’ and reduced attention to linguistic information evident in some individuals with ASD might be linked with better auditory processing skills (Heaton, 2003; Kuhl, Coffrey-Corina, Padden, & Dawson, 2005). A recent study (Bonnell et al., 2010) supports this suggestion, revealing superior discrimination of pitch in pure tones from people with autism having language difficulties, but not in those with Asperger Syndrome. Similarly, Jones et al. (2009) report enhanced discrimination of pitch in pure tones from individuals with a history of delayed language but also with a higher IQ.

Electrophysiological research investigating pitch perception in this population yields contrasting results. Some studies investigating the mismatch negativity (MMN)¹³ have found larger amplitudes in their subjects with ASD compared to the typically developing age matched controls, when presenting stimuli with changes in tonal pitch (Ferri et al., 2003; Lepistö et al., 2005) as well as vowel pitch (Lepistö, Nieminen-von Wendt, von Wendt,

¹³ The mismatch negativity (MMN) refers to the brain response when violations of a rule are presented. It is established by a series of sensory (typically auditory) stimuli (Näätänen, 1992)

Naatanen, & Kujala 2007) indicating better pitch processing in the former. Earlier and shorter MMN latencies to pitch changes in puretone stimuli (Gomot et al., 2002, 2010) as well as complex stimuli (Kujala et al., 2007) have also been reported in individuals with ASD, also indicating superior processing of pitch. On the other hand, studies have reported contrasting results specifically when the task demands are greater (O'Connor, 2011). Smaller MMN amplitudes in response to tonal pitch changes (Dunn, Gomes & Gravel, 2008) and more complex CV syllable pitch deviants (Kujala et al., 2010) have been observed, as well as delays in MMN in subjects with ASD (Jansson-Verkasalo et al., 2003, 2005).

Temporal duration processing in individuals with ASD has also been reported in the literature. Some studies investigating duration discrimination using pure tone stimuli through behavioural (Jones et al., 2009) and electrophysiological (Kasai et al., 2005) methods report no deficiencies in this skill, where the subjects with ASD perform similarly to the controls. Different results emerge when investigating duration discrimination within complex tones, where subjects with a diagnosis of Asperger Syndrome perform worse (Lepistö et al., 2006) or take longer to respond (Lepistö et al., 2007). Lepistö et al. (2005) also reveal impaired duration discrimination abilities to variations in complex non-speech vowel equivalents in children with ASD.

In addition to research on the performance of individuals with ASD on temporal processing skills, there has also been substantial interest with regard to their ability to perceive and understand speech in the presence of background noise. Difficulties in this skill have been commonly reported (Alcantara, Weisblatt, Moore, & Bolton, 2004); Egelhoff, Whitelaw & Rabidoux, 2005; Lane, Young, Baker, & Angley, 2010; Groen et al., 2009). Lane et al.'s (2010) study reports that a high percentage (92%) of children with ASD tend to get distracted or have trouble functioning in the presence of noise. It has also been found that these children perform worse than their typically developing peers in the perception of

sentences (Alcantara et al., 2004) and words-in-noise tasks (Groen et al., 2009) containing temporal dips within the background noise. Studies utilising electrophysiological or other objective methods disclosed consistent results. On examining transient evoked otoacoustic emissions (TEOAEs) to noise, Khalifa et al. (2001) observes atypical contralateral suppression in the group with ASD. The authors attribute this to non-normal activation of the medial olivocochlear efferents, which might impact the processing of speech in noisy environments. Studies have also been carried out investigating the processing of syllable sounds, in quiet and in noise, at the brainstem level (Russo, Nicol, Trommer, Zecker, and Kraus, 2009a) and at the cortical level (Russo, Zecker, Trommer, Chen, & Kraus, 2009b). Their findings show differences between the responses of the typically developing children and those with ASD both in quiet and noise leading to the conclusion that the children with ASD process speech syllables slower and with greater difficulty in both conditions. The authors of these studies (Russo et al., 2009a, 2009b) report that the auditory processing difficulties exhibited by the children with ASD is impaired to a greater extent than children with other developmental disorders such as LI dyslexia and ADHD.

Individuals with ASD frequently find it difficult to process and interpret auditory information accurately. Evidence for atypical processing of auditory information in ASD has been provided, both at behavioural and neural levels. The atypicalities are varied, ranging from atypical perception of simple tones such as pitch and loudness, to processing of more complex stimuli, like prosody. The trends across studies indicate a greater predisposition for poorer processing of complex auditory information, especially in stimuli using speech (O'Connor, 2011).

2.13 Summary and research questions

The review of the literature has highlighted the following points:

- With the lack of a current ‘gold standard’ for diagnosing APD and great variability across countries and centres in assessment, there is a need to develop a strong assessment battery having good validity and reliability measures.
- It is recommended that an AP behavioural assessment battery includes tests of both linguistic and non-linguistic auditory signals. The assessment battery should also incorporate the sub categories of AP, targeting dysfunction of the different neuroanatomical regions along the CANS. Dichotic listening tests, temporal processing and patterning tests, and tests of artificially degraded speech are some frequently recommended tests.
- While some AP skills have been reported to reach maturity by middle childhood, other auditory functions develop progressively until adulthood. This suggests that children tend to mature at different rates within and across AP measures.
- Bilingual speakers have been found to perform differently on subtests of AP in comparison with monolingual speakers.
- The symptoms frequently reported as characteristic of individuals with APD often tend to overlap with other neurodevelopmental disorders, such as poor attention and distractibility, language, literacy and/or communication difficulties, highlighting the need for a multidisciplinary approach to assessment.

Taking into consideration the above-mentioned points, the development of a sensitive tool that assesses APD in a specific bilingual population is rather challenging, albeit necessary. Thus, in relation to the targeted population for this research study, the following research questions were derived based on the objectives described in chapter 1.

1. How reliable and valid are the developed and modified tools of auditory and language processing?
2. How do typically developing Maltese children perform on tests of auditory processing? Do the independent variables affect performance in any of the tests?
3. How do typically developing Maltese children and those with different neurodevelopmental disorders perform on linguistic and non-linguistic tests of auditory processing?
4. What are the predictors of each subtest in the assessment battery of auditory processing in terms of the other subtests? Is there a relationship between any auditory processing subtest and (a) any language subtest (b) the questionnaire of (central) auditory processing?
5. What error patterns emerge in the typically developing children and those with reported listening difficulties on the tests of language processing?

Chapter 3. Methodology

3.0 Chapter overview

This chapter is sectioned into 3 main parts. The first part looks into the research methods and the associated statistical tests carried out. The second part gives an overview of the assessment battery of auditory processing. An explanation of the pilot study, consent and participant selection is given, followed by information on the general administration procedures. Subsequently, the reader is guided to a detailed description of all the tests used as part of the assessment battery.

3.1 Introduction to the research methodology

The types of assessment adopted for this research mainly include a questionnaire and psychometric assessment. The latter refers to methods of measuring an individual's relevant strengths and weaknesses and enables the assessor to attain an accurate understanding of the individual's cognitive abilities (PsychPress, 2014). The methodology adopted in this research study was a mixed-methods one, including both quantitative and qualitative analysis of the data. This research method has been found to provide added value to a study by increasing validity in the findings and supporting knowledge creation. Studies employing this approach open their doors to a deeper and broader understanding of the topic being investigated (Hurmerinta-Peltomaki & Nummela, 2006). Furthermore, the integration of quantitative and qualitative analysis yields more confidence in the results and conclusions drawn from a study (O'Cathain, Murphy, & Nicholl, 2010).

The focus of quantitative descriptive research is mainly the gathering and analysis of numerical data collected through questionnaires or assessments, with the further aim of offering trends applicable to a particular group of individuals. The descriptive element explains the fact that the subjects are only assessed once, as opposed to an experimental

quantitative study where the subjects are assessed before and after a treatment (Babbie, 2010). The disadvantage of a quantitative approach is that it might overlook certain contextual information. However, it is an effective way of testing hypotheses through statistical models (Neill, 2007). The questionnaire was designed to be quantitative in nature, enabling the assessor to bring out a score via a series of responses from a Likert scale. All other tests used and developed also measured quantitative data. In turn the assessor could obtain as precise a measurement as possible and further analysis of the target concepts (Neill, 2007) in relation to auditory processing abilities. On the other hand, the subtests in the assessment tool used to assess language processing also elicit responses of linguistic importance. Obtaining more in-depth qualitative data through a content analysis of the error patterns at the phoneme, word and sentence level would enable the exploration of new linguistic patterns in this population. Therefore, the combination of both quantitative and qualitative methods were used to encapsulate both the trends and details of the situation and produce a complete analysis (Creswell, Fetters, & Ivankova, 2004).

3.1.1 Study design. The study design adopted throughout this research included two main procedures. The principle design was through a cross-sectional method. A cross-sectional study is characterised by the fact that it is carried out at a specific point in time or over a short period. The main goal of this type of study design is to collect data on the individual characteristics of interest (Levin, 2006). Amalgamated with this design, the research looked into the effect of a number of independent variables on dependent variables. This is described as a factorial design (Shuttleworth, 2010). Through the factorial design the researcher was able to study the primary effects and interactions between two or more independent variables (known as factors) (Wright & London, 2009) as is depicted in table 1 below. It further allows many different values of the factor (known as levels) to be analysed. Therefore, in addition to emphasising the relationships between variables, it allows a single variable to be isolated and analysed individually (Shuttleworth, 2010). The effects of each independent variable on the dependent variables were examined in this research (examining effect of the independent variable ‘age group’ on the nonword repetition tests (NWRTs)), with the outcomes depicted in Chapter 5 (*Results – Quantitative Analysis*). A convergent parallel design was used on the subtests of language processing: the Maltese and English NWRTs in quiet (self-developed), and the Sentence Imitation Task (SIT) (Grech, Franklin & Dodd, 2011). This one-phase design employs both quantitative and qualitative methods simultaneously. In this design, quantitative and qualitative analyses are carried out separately. However, the qualitative analysis builds on the data obtained from the quantitative analysis to acquire a deeper understanding of the errors produced (see figure 1).

Table 1

Cross-sectional factorial design

	Factor	Levels		
Independent Variables	Gender	Male	Female	
	Age group (years)	7;00 – 7;11	8;00 – 8;11	9;00 – 9;11
	Primary Language	Maltese	English	
	School Type	State	Church	Independent
	Geographic region	North	South	
Dependent Variables	Tests with no linguistic content	Gaps in noise (GIN) (Musiek, 2003); Duration patterns test (DPT) (Musiek, 1984); Frequency patterns test (FPT) (Musiek & Pinheiro, 1987)		
	Tests with linguistic content	Dichotic digits test (DDT) (Musiek, 1983) (x2 – ‘free recall’ and ‘focused attention’); Nonword repetition test in noise (NWRT(n)) (x2 – Maltese and English based)		
	Tests of language processing	Nonword repetition test in quiet (NWRT(qu)) (x2); Sentence imitation test (SIT)		
	Questionnaire	The Questionnaire of (Central) Auditory Processing (QCAP)		

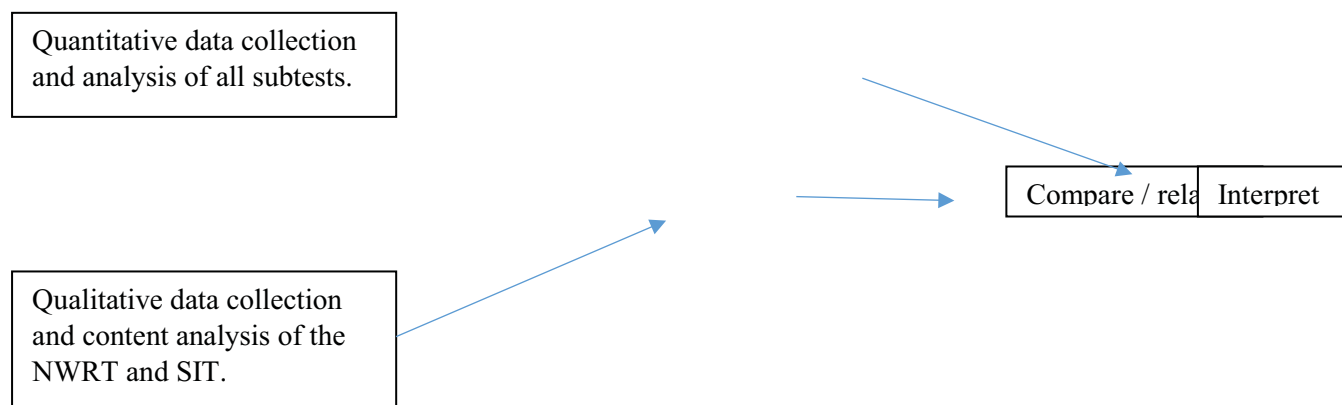


Figure 1 Mixed methods: The convergent parallel design

A second study design was used with 10 percent of the entire sample, in which a repeated measures design was used on the newly developed and modified tests of the assessment battery for the purpose of assessing their reliability and validity. This design required the same tests to be carried out at two points in time. A total of eight subtests (see table 2) underwent the repeated measures design: The Questionnaire of (Central) Auditory Processing (QCAP), the Maltese and English nonword repetition tests in quiet (mNWRT(qu) and eNWRT(qu)), the Maltese and English nonword repetition tests in noise (mNWRT(n) and eNWRT(n)), all of which were self-developed or adapted, and the three tests of temporal processing, namely the Duration Patterns Test (DPT) (Musiek, 1994), Frequency Patterns Test (FPT) (Musiek & Pinheiro, 1987) and the Gaps-in-noise test (GIN) (Musiek, 2003), whose methodology was modified. Therefore, this sample of the individuals completed the tests twice, leaving a gap of two weeks between test and retest.

Table 2

Subtests which underwent the repeated measures design

Subtest	Tests using linguistic content	Tests not using linguistic content
mNWRT(n)	√	
eNWRT(n)	√	
mNWRT(qu)	√	
eNWRT(qu)	√	
DPT		√
FPT		√
GIN		√
QCAP	NA ¹⁴	NA

¹⁴

NA – Not applicable (the questionnaire was given to the parent of the participants)

3.1.2 Choice of statistical tests. Following the data collection phase and the inputting of raw data it was necessary to select the appropriate statistical tests relevant to the data that have been collected, with the aim of answering the research questions posed in Chapter 2 (*Literature review*). The first step was to decide whether parametric or nonparametric tests were to be used. This depended on whether the data gathered were distributed normally or not (refer to Chapter 5, *Results - Quantitative Analysis*, for more detailed information). If the data were distributed normally, then parametric tests were used. Conversely, nonparametric tests were used when the data were not distributed normally (Kitchen, 2009).

3.1.3 Choice of statistical software. A substantial amount of statistical software packages are available on the market. Various articles have compared the available statistical packages (e.g. Mitchell, 2005; Wass, 2006; ProStatServices, 2012). The reader is referred to these articles for a comprehensive evaluation of the available software packages. For the purpose of this study, the researcher opted to use the Statistical Package for Social Sciences (SPSS) software, version 22. This is also the statistical software package recommended and used by the University of Malta for the analysis of quantitative data. SPSS has been reported to be relatively simple to use when compared with other statistical software packages (ProStatServices, 2012), while offering a comprehensive amount of analytical tests and descriptive statistics (Wass, 2006).

3.1.4 Data Analysis – Assessment Battery. The initial data analysis included a univariate statistical analysis; mainly bringing out the mean scores (central tendency) and standard deviations for all assessments of auditory processing. This type of analysis examines a single variable at a time. In this way, the frequency distributions were organised individually for each of the demographic factors – ‘gender’, ‘age group’, ‘primary language’, ‘geographic region’, ‘school type’, and ‘pathology’. In order to enter the data into the SPSS

software, it was necessary to code the data depending on the type of variable. Since SPSS requires all variables to be presented as numbers, the demographic factors such as 'gender' or 'primary language' were coded using 1 and 2, where 1 = 'male' / 'Maltese', and 2 = 'female' / 'English'.

In most cases the raw scores were converted into a percentage (%) accuracy score in the attempt to obtain consistent results throughout. This was especially valuable when similar tests were carried out using specific Maltese- and English- based phonotactic rules, such as the Maltese- and English-based NWRs in quiet and in noise. In this way the researcher was able to compare the performance of each child in the two languages.

A factor analysis was done to investigate which subtests were to be grouped in a category. Bivariate and multivariate statistics was then carried out to analyse the relationship between two or more variables. When comparing between two variables the t-test was the statistical test of choice if normal distribution was present. In cases where normal distribution was not present, the nonparametric equivalent (Wilcoxon Mann-Whitney U test) was used. When more than two variables were to be compared the Analysis of Variance (ANOVA) (parametric) or the Kruskal-Wallis test (nonparametric) was used.

Further statistical computations included correlation and regression analysis to examine the relationship between variables. Correlation analysis provides two important pieces of information: a) whether the relationship is a positive or negative one; b) the strength of the relationship (Wilson, 2009). Statistical correlation is measured through the coefficient of correlation (r). This is portrayed through a numerical range of between +1.0 to -1.0, with $r > 0$ indicating a positive relationship, $r < 0$ signifying a negative relationship, while $r = 0$ representing no relationship. The closer the numerical value is to +/-1.0 the stronger the correlation. The statistic algorithm used to analyse correlation analysis is the Pearson's

correlation coefficient (r). In the case of skewed data or data containing a number of outliers, the nonparametric equivalent is to be used – the Spearman's rho (r_s). Within this study it was of interest to examine whether any of the subtests were correlated with each other in any way and therefore correlation analysis was calculated between each subtest (NWRTs with the DDTs etc.). In addition to this, it was of interest to investigate the relationship between a dependent (the value to be predicted) and independent variable (the value used for prediction) and the impact of the independent variable on the dependent variable. This was done through regression analysis. There are two main types of regression analysis: linear and multiple regression. Linear models use just one independent and one dependent variable, while multiple regression models use two or more predictors. For the purpose of this study multiple regression analysis was performed. The *backward elimination* method was adopted for the regression analysis of each dependent variable. This analysis is often chosen when a researcher does not know which independent variables or covariates will be the best predictors of a dependent variable. In this method, all the predictors are entered into the equation simultaneously, followed by the elimination of the predictor with the coefficient of least significance (Kros & Rosenthal, 2016). A new model without this predictor is run again and the procedure is repeated until no nonsignificant predictors emerge (Black, 2011). Finally, only the variables with a significant value (p) of less than 0.05 were considered and used. The aim was to bring out the predictors (if any) of auditory processing abilities. The same form of regression analysis was carried out between dependent variables to investigate whether any subtests were predictors of other subtests.

3.1.5 Data Analysis – Questionnaire (QCAP). The questionnaire provided to the carers included ordinal data since the respondents were required to rate specific auditory skills on a scale of 1 to 5 – with a score of '1' referring to *no difficulty* and '5' meaning *substantial difficulty*. In this case it was possible to analyse the responses using descriptive

statistics in terms of both numerical and graphical illustrations such as tables, frequency distributions, and bar charts. The questionnaire responses were analysed in terms of the following independent variables: age group, gender, primary language, geographic, and school type. With the data collected from a clinical sample, the data were also analysed for further independent variable - pathology. A factor analysis was also carried out for the QCAP and in turn, the descriptive statistics were brought out separately for each factor where a statistically significant difference emerged between groups.

3.2 Tool Design and Development

To date there are no assessments of auditory processing that are standardised on the Maltese population. Tests of auditory processing are divided into two areas: tests using linguistic content, and those using non-linguistic content. Collecting data on the Maltese population is of importance with the aim of eventually standardising these tests.

Despite the bilingual variations in Malta (as explained in chapter 1, section 1.3), children are presently assessed for auditory processing using tests that are standardised on mainly British or American monolingual populations. Hence, any language-based tests are presented in American or British English via audio recordings. A bilingual speaker cannot be considered equivalent to a combination of two monolingual speakers (Grosjean, 1992) since the processing of speech and language in bilinguals is different to that of monolinguals (Niemi, 2010). A number of studies analysing both linguistic skills and neuroimaging processes have reported differences between monolingual and bilingual speakers. For example, Kaushanskaya, Yoo, Van Hecke, and Mirsberger (2009) found that bilingual individuals are able to acquire new words more efficiently than monolingual speakers. This could possibly stem from strong evidence that bilingual speakers possess differentiated dual lexicons, unlike monolingual speakers (Kovelman, Baker, & Petitto, 2008). Neuroimaging

studies have found bilingual speakers to have a larger amount of grey matter in the left inferior parietal lobe than monolingual speakers (Mechelli et al., 2004). Due to these differences, as well as culture diversities between populations (Fuente & McPherson, 2006), it is necessary to bring out data on the performance of bilinguals in these tests.

In addition to the AP tests using linguistic content, it is also of importance to obtain normative data for AP tests utilising non-linguistic content in a paediatric population. This is due to differences in neuromaturation and neuroplasticity of the auditory system of children under 12 years of age (Bellis, 2003). This importance is further augmented when studying auditory processing skills of bilingual populations.

3.2.1 The Assessment Battery of Auditory Processing. In light of the factors mentioned, the assessment battery was constructed to include 5 main sections, some of which consisting of further subtests:

- Section 1 is a questionnaire related to auditory processing skills / listening difficulties across different situations (initially developed for adults through an undergraduate project (Causon, 2010) supervised by the researcher, and further amended with permission to the paediatric population for this study (Appendix A-1);
- Section 2 consists of an audiometric screen, including otoscopy, pure tone audiometry, tympanometry, and acoustic reflex testing;
- Section 3 comprises the AP assessments using linguistic content, namely:
 - Test of Maltese nonword repetition in noise
 - Test of English nonword repetition in noise
(both these tests are newly developed by the researcher)
 - Two dichotic digits tests (Musiek, 1983)
 - Free recall of digits

- Recall of digits focusing attention to one ear;
- Section 4 includes the AP assessments using non-linguistic content. These are:
 - Duration patterns test (Musiek, 1994)
 - Gaps in noise test (Musiek, 2003)
 - Frequency patterns test (Musiek, 1994);
- The final section includes assessments of speech and language processing, namely:
 - Test of Maltese nonword repetition } (developed by the researcher;
 - Test of English nonword repetition } Calleja & Grech, 2014)
 - Sentence Imitation Test (taken from a local standardised assessment (LAMC) by Grech, Franklin and Dodd (2011).

Table 3 provides an overview of the processes each test assesses, and the areas of the brain to which it is sensitive.

Table 3

Tests of auditory processing

Test	Process Assessed	Sensitive to
Dichotic Digits Test (DDT) (free recall)	Binaural integration	Brainstem, cortical and corpus callosum lesions
Dichotic Digits Test (DDT) (simple focused attention)	Binaural separation (Silva & Dias, 2012)	Brainstem, cortical and corpus callosum lesions
Nonword repetition in noise	Auditory figure / ground auditory closure	Low brainstem and cortical lesions
Frequency Patterns Test (FPT)	Frequency discrimination / temporal ordering	Cortical lesions / interhemispheric transfer
Duration Patterns Test (DPT)	Duration discrimination / temporal ordering	Cortical lesions / interhemispheric transfer
Gaps in noise (GIN)	Temporal resolution	Cortical lesions / particularly left temporal lobe

Adapted from Bellis (2003); Cunningham

(2013)

The project was structured into sections, as explained in the research timeline (table 4).

Table 2

Research timeline

Date	Stage	Description
October 2010 – January 2011	Development phase	Construction of four nonword repetition lists. Nonwords are rated for word-likeness to Maltese or English separately through a Likert scale (between 1 and 5). (Rated by 20 adults).
February – April 2011	Pilot study	Test battery was tried out on 5 adults and 5 children. Amendments made to the questionnaire and the nonwords in noise tests
January 2011	Pre-data collection	Contact with National Statistics Office (NSO) to obtain the first 600 addresses, while waiting for acceptance from the ethics committees.
August 2012		NSO contacted again with a request to provide more addresses due to the low response rate.
September 2011 – September 2013	Data collection phase 1	Testing all children including typically developing (TD) and children with various difficulties. Each child attended two sessions lasting an hour each. Providing parents with questionnaires. 101 children were assessed in total.

October 2013 – May 2014	Data collection phase 2	Further testing on children with diagnosed neurodevelopmental disorders (including DLD, LitD, and ADHD).
July / August 2014	Data collection phase 3: Validation	Testing 10 children twice on the developed and modified tasks. Validation testing, test-retest reliability, and inter-rater reliability of parts of the assessment battery using the data collected during phase 3.

3.2.2 Ethical Issues. The researcher started the process of applying for ethics approval from the University Research Ethics Committee (UREC) at the University of Malta in October 2010. Simultaneously, a request for research in state schools was made to the Directorate for Quality and Standards in Education. This was refused on the grounds that the research was to be carried out in the Audiology lab at the Faculty of Health Sciences rather than in the schools themselves. In May 2011 an information letter was sent to the National Statistics Office (NSO) requesting permission to obtain addresses of families having children within the age range of the study. NSO accepted the request and the initial 700 addresses were randomly selected and sent to the researcher. UREC consent was obtained on the 21st March 2011 (reference number 023/2011).

3.2.3 The pilot study. A pilot study was carried out between February and April 2011. The assessment battery was tested both on 5 adults and 5 typically developing children. The reader is referred to table 7 for further details of the children tested.

The aim of carrying out the assessment battery on adults was to get an idea about how long it would take to complete all subtests, as well as to expose any shortcomings in the design of the procedure. The researcher was able to obtain feedback and gather information from the adult subjects in order to improve the quality of the test battery and method of administration. The first adult assessed was required to complete all five subtests in one

session. The session required a time frame of 1 hour and 45 minutes in order to complete the whole test battery. The subject commented that having to dedicate such a long amount of time to listening actively and focusing on what is being heard can be rather tiring. She also pointed out that the headphones used tended to become uncomfortable towards the end of each listening task and frequent breaks between tasks would increase the comfort during which one is attending to the task. Since the aim of the project is to assess children aged between 7;0 and 9;11 years, and with the knowledge that the attention span of children may be shorter than that of adults (Boyden & Ennew, 1997), it was decided that the assessment battery be carried out over more than one session. Two options were drawn up, specifically deciding whether to divide the assessment battery in two sessions of approximately 45 minutes each or three sessions of approximately 30 minutes each. The proposed layout of the two options is tabulated below (tables 3.5 and 3.6):

Table 3

Option 1 (duration 45 minutes per session)

Session 1 Assessment	Subtest	Author
Audiometric screen	Otoscopy Tympanometry Acoustic reflex testing Pure tone audiometry	
Non-speech-based tests	Duration Patterns Test	Musiek, (1994)
Speech-based tests	Dichotic digits (focused attention)	Musiek (1983)
	Nonword repetition in noise (list choice based on <i>secondary</i> language)	Developed by researcher
Assessments of phonological	Nonword repetition in quiet	Developed by

processing, language processing, and working memory	(list choice based on <i>primary</i> language)	researcher
	Sentence Imitation Test	Grech & Dodd (2010)
<hr/>		
Session 2		
Assessment	Subtest	Author
<hr/>		
Non-speech-based tests	Frequency Patterns Test	Musiek & Pinheiro, (1987)
	Gaps-in-Noise Test	Musiek, (2003)
Speech-based tests	Dichotic digits (free recall)	Musiek (1983)
	Nonword repetition in noise (list choice based on <i>primary</i> language)	Developed by researcher
Assessment of phonological processing	Nonword repetition in quiet (list choice based on <i>secondary</i> language)	Developed by researcher
<hr/>		

Table 4

Option 2 (duration 30 minutes per session)

<hr/>		
Session 1		
Assessment	Subtest	Author
<hr/>		
Audiometric screen	Otoscopy Tympanometry Acoustic reflex testing Pure tone audiometry	
Non-speech-based test	Duration Patterns Test	Musiek, (1994)
Speech-based test	Dichotic digits (focused attention)	Musiek (1983)
Assessment of language processing and working memory	Sentence Imitation Test	Grech & Dodd (2010)
<hr/>		
Session 2		
<hr/>		

Assessment	Subtest	Author
Non-speech-based test	Frequency Patterns Test	Musiek & Pinheiro, (1987)
Speech-based tests	Dichotic digits (free recall)	Musiek, (1983)
	Nonword repetition in noise (list choice based on <i>primary</i> language)	Developed by researcher
Assessment of phonological processing	Nonword repetition in quiet (list choice based on <i>secondary</i> language)	Developed by researcher
Session 3		
Assessment	Subtest	Author
Non-speech-based test	Gaps-in-Noise Test	Musiek (2003)
Speech-based test	Nonword repetition in noise (list choice based on <i>secondary</i> language)	Developed by researcher
Assessment of phonological processing	Nonword repetition in quiet (list choice based on <i>primary</i> language)	Developed by researcher

Three adults in the pilot study completed all subtests over two sessions, while the fourth and fifth adult completed the assessment battery over three sessions. Discussion with the subjects led to the overall opinion that two sessions were adequate to complete all tasks. However, short breaks between each test were important in order to rest physically from wearing the headphones for an extended period of time, and mentally due to the high level of auditory attention which one must give to each task.

3.2.3.1 The children in the pilot study. When approaching the children in the pilot study (characteristics shown in table 7), carers were asked to indicate their preference between bringing their child twice or three times to the research lab. Three carers specified that they would prefer it if their child could complete the test over two sessions due to their

busy lifestyle and other commitments. Two carers specified no preference. Hence, three children were tested over two sessions, while two children completed all subtests over three sessions as was shown in tables 3.5 and 3.6 above.

Table 5

Participant characteristics

Child	Age (years; months)	Gender	Number of sessions
1	8;2	M	2
2	9;9	M	2
3	7;6	F	2
4	9;11	M	3
5	8;7	F	3

The children were all given short breaks between each task while being briefed on how to complete the following task. The children who were required to complete the task in two sessions were able to do so in between 45 to 60 minutes. None of them showed any signs of fatigue towards the end of the session. It was therefore felt that it would be more feasible and time-saving to carry out the whole assessment battery over two sessions throughout the main project.

3.2.3.2 Feedback from the questionnaire of (central) auditory processing (QCAP).

Prior to commencing the listening tasks, the subjects were asked to complete a questionnaire related to auditory processing (as described in section 3.4 below). The QCAP included instructions at the top of the first page. However, the subjects showed that they felt more comfortable discussing exactly how they need to fill it in prior to doing so. In this way they would ensure filling it in correctly. In light of this, the researcher decided that throughout the main project the questionnaire will be given to the carers to fill in while their child is

completing the tasks. In this way she would be able to explain exactly what is required of them, and they would be able to ask for clarifications as they go through each question.

3.2.3.3 Modifications to the nonword repetition in noise test (NVRT(n)). As they progressed through the assessment battery the adult subjects also commented on the listening activities. A pitfall that was commented on frequently was that subjects found it difficult to pick out the signal from the noise (speech babble), despite the fact that the noise was set to be at an intensity of 5dB less than the signal. On deeper analysis of the noise used it was found that the intensity of the speech babble fluctuated, resulting in it masking the signal at intervals. This noise was therefore replaced with a speech babble sound file modified to keep a constant intensity throughout.

3.2.3.4 Modifications to non-speech based tests.

Gaps-in-noise. The GIN test includes four lists of equivalent difficulty, with each list consisting of 60 gaps ranging between 2 and 20ms. The researcher was debating whether to administer all four lists as part of the assessment battery or reduce it to two lists (one list per ear) as was the most common procedure carried out in previous research studies (Shinn, Chermak & Musiek, 2009; Prem, Shankar, & Girish 2012; Marculino, Rabelo, Schochat, 2011). As a trial, two lists were administered to all participants in the pilot study. The duration of completing these two lists was of approximately 30 minutes. It was observed that participants showed some signs of mental tiredness by the end of two lists, and the children tended to lose concentration at instances. The children were therefore given a short break between testing of the right and left ears. Opting to carry out all four lists would have been too time consuming and taxing on the participants. Inter-list equivalency has already been reported for the GIN. Musiek et al. (2005) as well as Samelli and Schochat (2008) have found no differences across the lists. Later, Hales (2016) confirmed interlist equivalency for the GIN when tested on Maltese children. Since the aim of this research was to develop an

assessment battery to be used in a clinic by busy clinicians, the time factor is of great importance. In light of this, two lists were presented throughout the main study.

It also emerged that the children (especially the 7-year-olds) found it difficult to understand the concept of identifying and counting the gaps. For this reason, the researcher attempted to request them to count the noise sections. So that if a 6-second interval of noise consists of two gaps then that would automatically result in three bouts of noise. Overall, the children seemed to find the task of counting the noise bouts (rather than the gaps) easier. This approach was hence taken throughout the main study.

Duration Patterns Test. This task required the participants to listen to a sequence of three pure tones of frequency 1000Hz with two different durations - short 250ms and long 500ms and six different combinations, ‘‘long, short, long’’, ‘‘short, long, long’’ etc..

Modifications to this test included the following:

1. The original test consists of 60 items. This was shortened to 30 items for the purpose of this study due to the fact that
 - a. The children lost concentration listening to 60 sets of pure tones.
 - b. It was necessary to reduce the time of the assessment due to the length of the overall test battery
2. In previous studies, subjects were asked to verbally explain the tone sequence heard (Musiek, Baran, & Pinheiro, 1990; Coticchia, Roeder, Zuliani, Gow, & Garbern, 2011; Ajith, Syed, & Sangamanatha, 2012). The adults completing the task had no difficulty with this task. However, most children found difficulty verbally explaining the tones heard and at times resorted to guessing the sequence. At this stage the researcher requested that they hum the sequence. However, this resulted more often than not in them not clearly showing a distinction between the long and short tones.

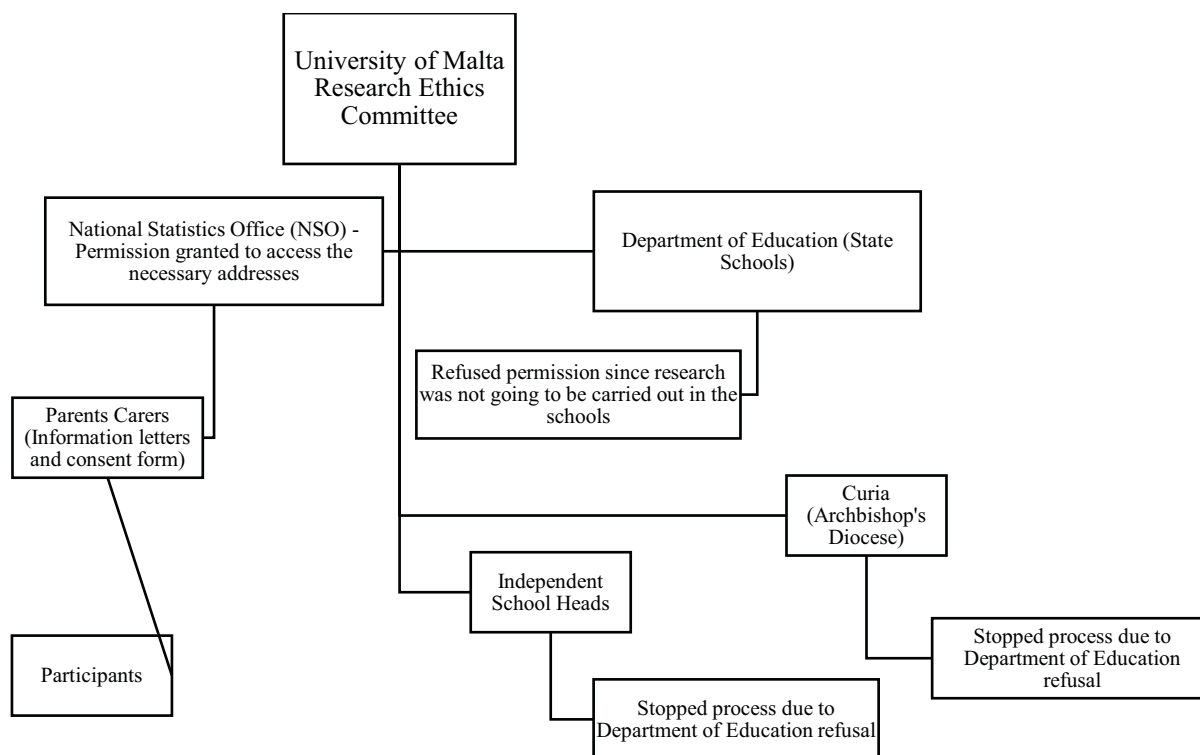


Figure 2 Process of participant selection

3.3.2 The sampling procedure. It was the initial aim of the researcher to obtain a representative sample of the total population of children aged between 7;00 and 9;11 years, which amounts to 12,086 children (NSO, 2014). However, for this population size and considering a confidence level of 95% and margin of error of 5%, the number of subjects needed to participate would amount to approximately 370 (amount calculated through The Research Advisors, 2006). While considering the time frame allocated for this study and the amount of time dedicated to each participant (2 hours) to complete the test battery, the researcher reduced the target amount to 200 typically developing participants with the aim of bringing out trends in the performance of auditory processing tasks. In the first year of the study a total of 700 letters were sent as shown in table 8. Each envelope pack sent to the potential participants' carers contained an information letter explaining the study, a consent form, and a self-addressed stamped envelope. Both information letter and consent form were

written in Maltese and English. The number of returned and accepted consent forms is also outlined in table 8

Table 6

Participant selection and turnout – October 2011 to June 2012

Date	Number of information letters / consent forms sent	Number of consent forms returned	Number of participants that turned up for the study	Number of participants who did not satisfy the inclusion criteria ¹⁵
01.10.2011	100	7	7	1
01.11.2011	100	9	8	1
09.01.2012	100	9	9	2
08.02.2012	100	12	9	2
15.03.2012	100	7	5	1
20.05.2012	100	5	5	1
20.06.2012	100	1	1	0
TOTAL	700		44	8

Throughout the first year of the study, the pattern of a very low response rate emerged throughout (6.3%). The researcher requested once again further addresses from the NSO. Another 750 addresses were randomly selected, excluding the ones that were selected in the previous year. Table 9 outlines the participant selection and turnout throughout the second year of the project.

¹⁵ Note: Due to the low response rate these children were still tested and their data used to as part of a clinical population group

Table 7

Participant selection and turnout – October 2012 to June 2013

Date	Number of information letters / consent forms sent	Number of consent forms returned	Number of participants that turned up for the study	Number of participants who did not satisfy the inclusion criteria
15.10.2012	150	12	11	1
28.11.2012	150	9	9	0
15.01.2013	150	13	10	3
25.03.2013	150	10	9	3
06.05.2013	150	12	9	2
TOTAL	750		48	9

The response outcome to the information letters sent out throughout the second year was also very poor, with a percentage of 6.4%. Due to the time restriction allowed for this study it was decided to collect some more data through snowball sampling. Nine typically developing subjects and 13 children to form the clinical group were further recruited. The data collection was terminated following this. A total of 131 subjects completed the testing, 30 of which (18.5%) were known to have difficulties including ADHD, literacy difficulties, and a history of a developmental language delay or disorder.

The initial aim of the study was to include only typically developing children according to the participant selection criteria outlined in table 10.

Table 8

*Participant**selection criteria*

Characteristics for selection criteria
1. Maltese citizen
2. Aged between 7;0 and 9;11 years
3. Primary language: Maltese or English
4. No sensory impairment
5. No history of hearing impairment / chronic ear infections
6. No speech and language impairment
7. No cognitive impairment
8. No attention difficulties
9. No neurological pathology
10. No behaviour problems
11. No long term medication

However, due to the low response rate the decision was made to include all participants and analyse the data of the clinical group separately. These data were to be used for comparative purposes. The clinical group consisted of 30 children with varied reported diagnoses as shown in table 11

Table 9

Clinical sample

Impairment	Number of children
Literacy difficulties	9
ADHD	4
Combined literacy difficulties and ADHD	5
Information processing difficulties	2
Global developmental delay / low cognitive ability	3
Combined literacy difficulties and a history of speech and language delay/impairment	4
Combined mild hearing loss and literacy difficulties	2
Mild autism spectrum disorder	1
Total	30

3.3.3 Participant characteristics. Figures 3.3 and 3.4 provide an outline of the amount of TD children in each category. Out of the total TD sample, 42 were male and 59 were female. More individuals from the North of the island (77 participants) showed interest in participating in this study when compared to individuals from the South (24 participants). Overall, most children attended mainly state or church schools, with the amount attending state schools (41) being slightly more than church schools (36). Fewer children were reported to attend independent schools (24). The primary language (PL) was found to vary between schools. In state schools more children spoke Maltese (85%). Similarly, most children attending church schools used Maltese as their primary language. However, this was less than in state schools (64%). The language use of children who attended independent schools portrayed a different picture, with the vast majority (92%) using English as their primary language.

Total 101																	
Male 42																	
North 34									South 8								
State 17			Church 7			Independent 10			State 3			Church 4			Independent 1		
7:00-7:11 2	8:00-8:11 8	9:00-9:11 7	7:00-7:11 3	8:00-8:11 4	9:00-9:11 0	7:00-7:11 2	8:00-8:11 3	9:00-9:11 5	7:11-7:11 0	8:00-8:11 3	9:00-9:11 0	7:00-7:11 1	8:00-8:11 3	9:00-9:11 0	7:00-7:11 0	8:00-8:11 1	9:00-9:11 0
M t 2	En 0	M t 6	En 2	M t 6	En 1	M t 1	En 2	M t 3	En 1	M t 4	En 0	M t 0	En 2	M t 0	En 3	M t 1	En 4
M t 2	En 1	M t 1	En 0	M t 2	En 1	M t 1	En 0	M t 2	En 1	M t 1	En 0	M t 1	En 0	M t 1	En 0	M t 1	En 0

Figure 3 Distribution of male participants across school type, age, and primary language

Total 101																													
Female 59																													
North 43									South 16																				
State 11			Church 20			Independent 12			State 10			Church 5			Independent 1														
7:00-7:11 5	8:00-8:11 1	9:00-9:11 5	7:00-7:11 9	8:00-8:11 5	9:00-9:11 6	7:00-7:11 5	8:00-8:11 3	9:00-9:11 4	7:00-7:11 3	8:00-8:11 2	9:00-9:11 5	7:00-7:11 3	8:00-8:11 2	9:00-9:11 0	7:00-7:11 0	8:00-8:11 1	9:00-9:11 0												
Mt 4	En 1	Mt 1	En 0	Mt 3	En 2	Mt 5	En 4	Mt 2	En 3	Mt 4	En 2	Mt 0	En 5	Mt 0	En 3	Mt 0	En 4	Mt 3	En 0	Mt 2	En 0	Mt 5	En 0	Mt 3	En 0	Mt 2	En 0	Mt 0	En 1

Figure 3 Distribution of female participants across geographic location, school type, age, and primary language

Figure 5 provides the distribution of the clinical group in the demographic factors. In contrast to the TD sample there were more males in the clinical group (60%). There was a slightly higher proportion of PL Maltese-speaking children (57%). While the majority of the males in this group attended a state school, the opposite emerged in the females, where a higher number attended an independent school. Similar to the TD sample, a higher proportion of the PL Maltese speaking children attended a state school. All the children attending an independent school used English as their PL.

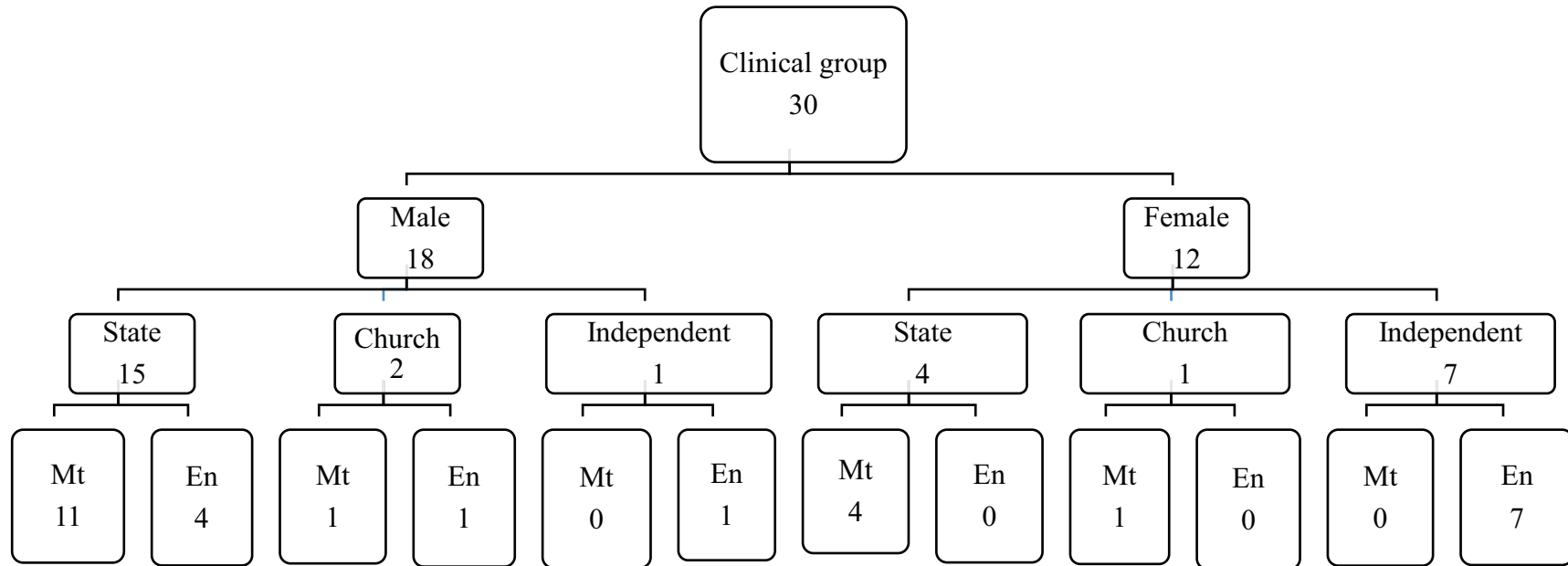


Figure 4 Distribution of clinical group across gender, school type, and primary language

3.3.4 General administration procedures. All tests in the assessment battery were carried out by the researcher. However, the 10 subjects whose data were used for reliability and validity testing were assessed by 4 research assistants. The administration of the entire assessment battery lasted two hours per participant. This was divided in two sessions lasting one hour each. The tests were all administered on an individual basis. Before initiating the testing the researcher took down details in relation to the participants' preferred language, where they lived, and which school they attended.

Each session encompassed six subtests. The participants were given short breaks between each subtest while the researcher explained the next task. In each session it was ensured that the tasks were varied to include both speech-based and non-speech-based tests, and balanced in terms of difficulty level. The combination of the individual tests carried out per session was tabulated in table 5. The order of subtest administration was randomized in order to minimise the possibility of order effects (mainly due to fatigue).

3.4 The Questionnaire of (Central) Auditory Processing

The *Questionnaire of (Central) Auditory Processing* (appendix A-4) was designed and provided in both Maltese and English. The main objective of running this questionnaire was to obtain information regarding the behaviours that may be present in individuals with auditory processing difficulties, based on previous literature (e.g. Heine & Slone, 2008; Iliadou et al., 2017; Jerger & Musiek, 2000). The aim of developing this tool was so that it could be used as an informational tool for clinicians to acquire an understanding of carers' views about the child's difficulty with auditory tasks. The information obtained in this questionnaire was valuable in obtaining a behavioural profile of children's auditory skills, as well as correlating the carers' perspectives of their child's auditory skills with the other

behavioural tests in the auditory processing assessment battery. It was also useful in identifying factors related to the posed inclusion / exclusion criteria.

Questionnaires are valuable tools that enable the researcher to translate the information required into an array of specific questions, in which respondents are able to answer. It is a useful way of collecting quantitative primary data (Malhotra, 2006), and in turn explore respondents' preferences and draw out trends in perspectives. Questionnaire use has both its advantages and disadvantages: One advantage is that when compared to other forms of assessment, questionnaires are a relatively inexpensive method of collecting information (Bernsen & Dybkjær, 2009; Walonick, 2004). In addition, they make certain that all respondents are exposed to the exact same questions, reducing variability with which statements are presented and in turn interpreted (Bernsen & Dybkjaer, 2009). Finally, they facilitate data entry and subsequent analysis (Walonick, 2004). A disadvantage to questionnaires is that due to their written nature respondents are not able to interpret any intonation, gesture or facial expression (Bernsen & Dybkjaer, 2009). Many questionnaire types (as the one used in this project) are also inflexible in the way they allow respondents to reply. In order to overcome this disadvantage, respondents were required to fill out the questionnaire while their child was being assessed. In this way the researcher was able to explain how the questionnaire was to be filled and answer any queries that they might have had. Another disadvantage to questionnaires is the possibility of a low response rate (Walonick, 2004). This was unfortunately the case with this study, which was possibly also due to the fact that the carers asked to fill out the questionnaire were also required to bring their child to the research lab to carry out the assessment battery. On the other hand, the researcher was able to collect completed questionnaires from the parents of all the children who participated in the study. A third shortcoming, and one that also emerged in this study, is that some people find it difficult to fill out questionnaires due to illiteracy. This difficulty

was overcome in the project, where the researcher explained what was required, read out the statements and the respondent replied verbally. The researcher then wrote down the responses accordingly.

The first draft of this questionnaire was adapted to the local situation by Causon (2010) and was based on work carried out by Rosenberg (1998). Rosenberg (1998) put together a list of characteristics observed by parents and teachers in children reported to have a difficulty with auditory processing. In this study, Causon's (2010) questionnaire was further adapted to target the Maltese paediatric population.

Questionnaires can be structured in different ways, with the most common being close-ended questions (such as a Likert scale or a semantic differential scale) and open-ended questions (Bernsen & Dybkjær, 2009). For the purpose of this project the researcher opted to use a structured, close-ended questionnaire, with the intention of analyzing responses quantitatively. *The Questionnaire of (Central) Auditory Processing* consists of a total of 25 close-ended questions. The first five questions were created in order to obtain parental report of their child's developmental history concerning ear infections, hearing loss, and related difficulties that have been found to cause similar behavioural characteristics as those observed in individuals with auditory processing difficulties (such as LitD, ADHD, DLD, ASD) (refer to chapter 2: literature review, section 2.12 for further details). In these five questions carers were required to reply by simply indicating 'yes' or 'no' below the statement. The following 20 questions targeted various auditory skills as shown in table 12. Throughout this part of the questionnaire, carers were required to answer each statement by choosing a grade between 1 and 5, according to the level of agreement with it. Grade 1 indicated that the statement was not relevant to their child; whilst Grade 5 indicated the highest level of relevance.

Table 10

Auditory skills highlighted in the QCAP

Auditory Skill	Question numbers
1 : auditory attention and memory	6, 13, 14, 15,18, 20, 22, 24, 25
2 : following conversations	9, 16, 19, 23
3. Listening in noisy situations	7, 8
4 : sensory stimulation	10, 12
5 : social aspects	17, 21

At the end of the questionnaire, the carer was required to indicate which language their child feels more comfortable speaking; whether it was Maltese, English, or no particular preference. The researcher verified this through discussion and questioning the child specifically later in the data collection stage. This knowledge was necessary for the researcher to take note of, especially since part of the assessment battery of AP included tasks using linguistic content. Furthermore, the subjects were also screened for language processing and this was to be carried out in their primary language.

3.4.1 Translation of the Questionnaire of (Central) Auditory Processing. The bilingual context in Malta requires that questionnaires are provided in both Maltese and English. The QCAP was constructed and developed using the English language. For this reason it was necessary to go through the procedure of translating it into the Maltese language.

The process of translating a well-established tool can subject the translated tool to test bias. The three main types of test bias are construct bias, method bias, and item bias (Van de Vijver & Tanzer, 2004). The former two are mainly concerned with cultural effects that can affect the validity of a tool. The researcher opted to develop an entirely new questionnaire of auditory processing, which although poses to be difficult and time consuming (Bornman, Servick, Ronski, & Kyeong Pae, 2010), eliminates as much as possible these cross-cultural

differences that lead to test bias. Briefly; construct bias arises if the concept measured is not alike across cultural populations. Method bias occurs when there is incomparability between groups on characteristics. For example, Hui and Triandis (1989) had found that Hispanic groups tended to choose extremes on a five-point rating scale more often than White Americans. Method bias also arises when there are communication issues between interviewers and interviewees, such as, when they differ in their first language and cultural background (Van de Vijver & Tanzer, 2004). The third type of bias – item bias – is more concerned with distortions at the item level and occurs through inadequate translation choices (Van de Vijver, & Hambleton, 1996). Errors at this level can change the way respondents interpret the meaning of the question. Hence, the respondents may be knowledgeable about the concept of interest, but would be inhibited from showing what they know (Gierl, Rogers, & Klinger, 1999).

In order to limit the introduction test bias during the translation process, equivalence of the material was pursued. Two specific linguistic units are considered equivalent when a unit in one language conveys the same meaning as was intended when allotted in a specific linguistic medium in a different language (Karimi, 2006). The main aim when translating an assessment tool is to (as much as possible) obtain measurement equivalence (Gjersing, Caplehorn, & Clausen, 2010), while keeping in mind that an exact equivalence is difficult to achieve (Nababan, 2008). This is due to the fact that it is difficult for a piece of writing to have unvarying interpretations (even by the same individual) on two occasions (Hervey, Higgins & Haywood, 1995). Furthermore, translation is dependent on subjective interpretation of translators. So creating the same effect on the target text readers as that on the source text readers is challenging (Nababan, 2008).

During the translation process, five types of equivalences have been described via the conceptual model. This model suggests that achieving equivalence among cross-language and

cross-cultural forms of an instrument can be attained by acquiring proof of their semantic, content, technical, criterion and conceptual equivalence (Flaherty, Pathak, Mitchell, Wintrob, Richman, & Birz, 1988). Each of these equivalence types are described briefly below. Since the population being examined in this study is a bilingual one, the most important and relevant equivalence type to be analysed is the semantic equivalence as it is mainly concerned with the linguistic meaning of the items. The remaining equivalence types are more concerned with cross-cultural equivalence. They would therefore be less applicable to this study since the population is one and the same, with the same cultural background and the only difference being the primary language used.

Semantic equivalence denotes how the meaning of each item in the measurement tool is retained after translation from the source to the target language (Chavez & Canino, 2005). Semantic equivalence aims to safeguard that the linguistic meaning and words included in each item and instructions of the tool are the same in both source and target languages (Pena, 2007). The focus is more on the semantic expression of language rather than a direct translation of the linguistic form in the source language. Semantic equivalence must first be established before other equivalence types can be attained (Liu, 2008).

Content equivalence measures how relevant each item is to the target language (Fawcett & Garity, 2009). It ensures that the tool analyses the same construct (Pena, 2007) and focuses on whether or not the item is correctly perceived by the target population vis-à-vis their cultural background (Liu, 2008). Technical equivalence assesses whether the method of data collection for the two versions of the tool is similar in each culture (Liu, 2008) and the extent to which it is comparable (Fawcett & Garity, 2009). When the source and target cultures are familiar to the format of the tool administration (a questionnaire) it would not be necessary to test for technical equivalence (Flaherty et al., 1988). Criterion equivalence examines the ability of a tool to interpret the data in a similar way to each culture's

established norms (Fawcett & Garity, 2009). It further analyses whether the tool's correlation with established independent criteria is the same across cultures (Chavez & Canino, 2005). Conceptual equivalence safeguards that the theoretical construct remains equivalent in each culture (Liu, 2008).

Another type of equivalence worth mentioning is the metric (or experiential) equivalence (Kristjansson, Desrochers, & Zumbo, 2003). This involves analysis of equivalence in the difficulty of an item between languages. Some items found in the source language could present with a certain level of difficulty. However, when translated in the target language the same item could depict a different level of difficulty (Pena, 2007).

Taking into consideration the different forms of equivalence relevant to the development and translation of a particular tool aids in obtaining more valid conclusions from the instrument, representative of the target population (Kristjansson et al., 2003).

The questionnaire was translated in the following steps:

3.4.1.1 Preparation of the tool. The first draft of the questionnaire was developed by Causon (2010) as part of an undergraduate dissertation. This draft was used to investigate auditory processing skills in adult listeners. For this study, the researcher adapted the questions to target parents and carers of a Maltese paediatric population.

3.4.1.2 Forward translations. The translation of the QCAP was carried out by two bilingual Maltese-English individuals living in Malta. This was a necessary requisite in order to obtain a good translation of the text, since a good translation requires mastery in the source and especially the target languages (Neubert, 2000). The translator must accurately understand the meaning and the intention put across by the author of the source text (Kaur & Singh, 2005).

Both translators were certified in English to Maltese translation. The translators carried out the first translation independently, resulting in two versions of the English text into Maltese. The development of the two separate versions enables exposure of errors and a diverse interpretation of any possible unclear terms which might be present in the source text. In turn, any potential biases would be reduced (Wild et al., 2005).

3.4.1.3 Reconciliation. The two independent translated versions were reviewed by a third independent translator and proof reader in order to examine for any discrepancies between the two versions and look for agreement between the individual preferences. Reconciliation helps avoid a biased translation which would be written in one individual's personal style, resulting in translation misinterpretations (Wild et al., 2005). The third person chosen was a native speaker of the target language (Maltese), and also fluent in the source language (English). Furthermore, this proof reader was not involved in any of the forward translations.

3.4.1.4 Back translation and review. The third version brought out through the reconciliation phase was back translated into the source language – English. The chosen back translator was a certified translator whose native language was the same as the source measure. The individual was also fluent in the target language. The back translator had no prior knowledge of the original text and was not given access to the source version before and during the back translation. The back translated version of the questionnaire was reviewed and compared with the original text in order to ascertain the conceptual equivalence of the translated text. The researcher looked for any discrepancies between the two versions and confirmed that with the exception of some literal differences between the texts, the two versions were equivalent.

The final version was read by two bilingual adults, who provided feedback on their understanding and interpretation of the items in the Maltese version of the questionnaire.

Any relevant feed-back obtained was considered by the researcher and further minor amendments were made. This final version (appendix A-4) was used in the study.

3.5 The audiometric screen

It has been recommended that detailed audiometric tests, including pure tone audiometry, tympanometry, and acoustic reflexes are carried out prior to the assessment battery of auditory processing (BSA, 2018). Knowing the status of an individual's peripheral auditory system could determine the influence on the central auditory function (AAA, 2010). A number of studies have found that a peripheral hearing loss may result in a negative impact on the performance in an assessment of auditory processing (Divenyi & Haupt, 1997; Neijenhuis, Tschur & Snik, 2004). From another clinical perspective, in the situation that difficulties with auditory processing are evident, it might be of importance to differentiate between APD and similarly presenting auditory disorders such as Auditory Neuropathy Spectrum Disorder (ANSD) (BSA, 2011b).

All the participants in the study underwent an audiometric screening prior to the assessment of auditory processing. All audiometric testing (as well as APD testing) was carried out in a quiet room with a background environmental sound of approximately between 30 and 33 dB A. The screening included tympanometry, acoustic reflex thresholds, and pure tone audiometry. An Interacoustics clinical audiometer AC33 with TDH 39 supra-aural head phones was used to carry out pure tone audiometric tests. Each participant was required to listen to pure tones presented in each ear, press a button as soon as they hear the tone, and let go of the button when the tone ceases. The tones were presented in each ear separately at the frequencies 1000, 2000, 4000, 8000, 500, and 250Hz. At each frequency the tone was first presented at a comfortable loudness level of 50 dBHL and thereafter reduced in steps of 10 dB until the subject did not hear the tone anymore. In this way the threshold of

hearing was found at each frequency in order to ensure bilateral normal hearing levels (below 20 dBHL; BSA, 2011c) across all frequencies. Tympanometry was conducted bilaterally using a GSI Tymp Star immittance unit. For the purpose of this project a continuous 226 Hz tone was used (since multiple frequency tympanometry is only used on infants less than six months of age). The results obtained were compared with documented normative data, i.e. a peak compliance of 0.3 to 1.4cc, an ear canal volume of between 0.6 to 1.5ml, and an ear canal pressure of -150 to +25 daPa (Margolis & Heller, 1987). Acoustic Reflex Threshold (ART) was also carried out using the same equipment as the tympanometric tests. The measurements were performed ipsilaterally at 500 Hz, 1000 Hz, 2000 Hz and 4000Hz at stimuli of between 80 and 100 dBHL. The ART thresholds were considered normal when a response of 0.02ml was obtained at each frequency.

3.6 Auditory processing subtests using linguistic content and language processing tests

The AP tests that incorporate linguistic content as their signal include two tests of dichotic listening and two tests of nonword repetition in noise (one based on Maltese phonotactics and the other based on English phonotactics). The tests of language processing include the Sentence Imitation Test (Grech, Franklin & Dodd, 2011), and two tests of nonword repetition in quiet (also based on Maltese and English phonotactics). These lists were developed simultaneously with the tests of nonword repetition in noise. The construction of the nonword lists and assessment design is described in section 3.6.2 below, followed by a description of the Sentence Imitation Test.

3.6.1 Dichotic digits test (DDT) (Musiek, 1983). The dichotic digits test assesses auditory integration and divided attention (Hough, Givens, Cranford, & Downs, 2007), as it

requires an individual to divide his/her attention between two ears (Bouma & Gootjes, 2011). The test uses all numbers between 1 and 10 (except 7, since it is a two-syllable word unlike the rest). The test numbers are presented in English. The researcher opted to use the original recording rather than an adaptation of this test. This was due to the fact that generally, Maltese children (including those whose primary language is Maltese) tend to learn and use numbers in English first. Although the Maltese-English accent is different to the American-English accent used in the DDT recording, children in Malta tend to be accustomed to this different accent due the readily available American child oriented programs. In turn, it was assumed that all children would be comfortable repeating numbers heard in American-English.

In the DDT, pairs of digits are presented to the right ear, while simultaneously, a different pair of digits are presented to the left ear through a calibrated audiometer at an intensity of 50 dB HL (Musiek, Baran & Shinn, 2004). An illustration of this can be seen in figure 6 below. For this project, the recording was obtained through AUDiTEC Inc.

Prior to initiating the test, the audiometer was calibrated using a 1000Hz tone. This was followed by two or three practice trials to ensure that the participants understood what was expected of them. If a participant did not understand the concept of the test, the instructions were given again and the practice digits re-presented.

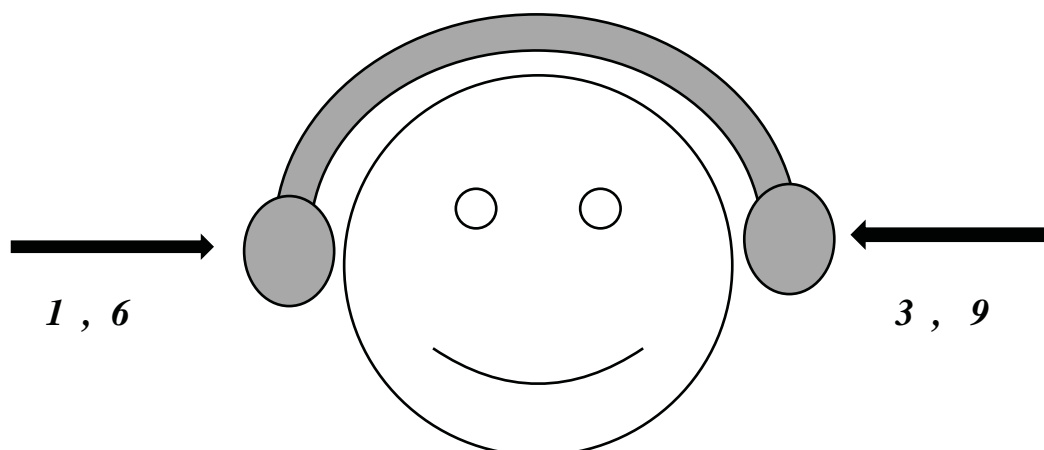


Figure 5 Schematic diagram of Dichotic Digits presentation

The DDT included two sub-categories, namely the free recall test and the simple focused attention test. Both these tests used double digits as a stimulus. The free recall test required the participants to integrate information presented to each separate ear and then repeat back all four numbers (Hough et al., 2007). The simple focused attention task required the participants to focus either on their right or their left ear, and repeat only the two digits that were presented in that identified ear, i.e. the ear which the researcher would have instructed the participant to attend to (Hough et al., 2007). Some research studies also incorporate a more complex focused attention paradigm, in which participants are requested to first focus their attention and recall the digits from that ear (i.e. the attended ear) and then mention the two numbers that were heard in the unattended ear (Bouma & Gootjes 2011). This was attempted with the children who took part in the pilot study. However, they all were observed to struggle with this more complex task and therefore the researcher opted to use the simple focused attention task as part of the assessment battery.

The free recall test included a total of three trial items and 20 test items, while the simple focused attention consisted of two trial items and 18 test items. All correct responses were taken note of and a percentage of correct identification score for each ear was calculated.

3.6.2 Nonword repetition tests. Of primary importance in the development of the nonword repetition tests in quiet and in noise was a child-friendly test that is straightforward and quick to use as a clinical tool. The administration of a nonword repetition test requires the child to repeat auditorily presented nonsense words (Jones, Tamburelli, Watson, Gobet & Pine, 2010), based on the phonology of the specific language.

3.6.2.1 Build-up of nonwords. The nonword lists were based on both the Maltese and English segmental phonology and phonotactic rules. A nonword is a phonetic sequence which does not make up a meaningful word but is made up of acceptable phonotactic rules and syllabic combinations to a specific language (Zevin & Joanisse, 2000). A nonword repetition task utilises numerous levels of processing, including “auditory decoding, phonological processing, working memory, speech motor planning and execution” (Sasisekaran, Smith, Sadagopan, & Weber-Fox, 2010, pp. 521), all of which occur in a continuum (Richard, 2007). Nonword repetition tasks are frequently used as part of an assessment battery for DLD since specific features in the nonword can help to discriminate between the accuracy in repetition of typically developing (TD) children and children with DLD.

The aim was to choose an assessment that would tap into auditory processing and phonemic processing, while eliminating as much as possible the use of language processing related to syntax and meaning. The criteria on the construction of a nonword repetition test have been deeply discussed throughout the COST Action ISO804, in which the researcher was involved. The aim of this Action was an attempt to bring out the salient features of nonwords and develop a common ‘backbone’ upon which nonwords across different languages are developed. These features are discussed below.

Syllable Length. Studies (Archibald & Gathercole, 2006; Jones et al., 2010; Marton & Schwartz, 2003) show that as the number of syllables in the nonword increases, the greater the difficulty exhibited by both typically developing (TD) children (Calleja & Grech, 2014) and to a greater extent in children language difficulties (Jones et al., 2010; Munson et al., 2005). A greater discrepancy in accuracy between the TD and children with DLD is evident in the longer items (3 and 4 syllable nonwords). On the basis of this finding, it is important that the test consists of nonwords reaching up to four syllables.

Single consonants versus consonant clusters. Another characteristic in the production of nonwords is the inclusion of consonant clusters in the nonwords. Studies analysing the production of consonant clusters in children have found that children with language difficulties produce more errors in these nonwords when compared with the repetition of nonwords incorporating only single segments (e.g. Archibald & Gathercole, 2006; Gallon, Harris & van der Lely, 2007; Marshall & van der Lely, 2009).

Phonotactic probability, word-likeness and lexicality. A third characteristic of importance is the notion of phonotactic probability and high versus low lexicality nonwords. The term phonotactic probability refers to “the frequency with which a sequence of phonemes occurs in the lexicon of a language” (Munson et al., 2005, p. 1034). It can be explained as the probability of how a particular sequence of phonemes occurs in a language. High-probability sequences of phonemes can be found in numerous real words (such as /ft/ in English) (Munson et al., 2005). Conversely, low-probability sequences occur in fewer real words (such as /fk/ in English).

Phonotactic probability in the English language is well documented (Frisch, Large & Pisoni, 2000; Storkel, 2001). There has also been research carried out on phonotactics in relation to bilingual speakers (Frisch, Brea-Spahn & Orellana, 2008; Frisch & Brea-Spahn, 2010). The authors looked at the metalinguistic judgements of phonotactics by bilingual Spanish-English individuals. They found that most of the bilinguals performed similarly to monolinguals in each language. There was also presence of cross-language influences in how the subjects judged how well-formed the nonwords were. Nonetheless, these seemed to reflect individual experience with a language and was dependent on the lexical knowledge of each individual. A strong linear relationship between phonotactic probability and word-likeness has been frequently reported (e.g. Bailey & Hahn, 2001; Frisch et al., 2000; Hay, Pierrehumbert, & Beckman, 2003; Treiman, Kessler, Knewasser, Tincoff, & Bowman, 2000).

The term ‘word-likeness’ refers to the similarity of a nonword stimulus to a real word in a person’s native language (Frisch et al., 2000; Munson et al., 2005).

To date no known research has been carried out on phonotactic probability and lexicality in relation to the Maltese language. Jones et al. (2010) compared the lexicality of English words with word-likeness and found a linear relation between them. In their study 11 adults were presented with the spoken form of all nonwords and asked to rate them on a 5-point Likert scale (1=nonword-like, 5=word-like). The results were that the low-lexicality nonwords were perceived as significantly less word-like in comparison with high lexicality nonwords. For the purpose of this study, the nonword repetition lists in quiet and in noise were developed using both perceived high and low lexicality nonwords. The aim of this was to open an opportunity for further investigation as to whether the subjects performed differently when repeating words of high word-likeness as opposed to low word-likeness. In order to do this, two separate lists of 72 nonwords (one using Maltese phonotactics and the other using English phonotactics¹⁶) were developed. The nonwords varied between two- and four- syllables. Half of them included consonant clusters (two adjacent consonants with no syllabic division) while the other half included only single consonant (CV...) or consonantal sequence (two adjacent consonants with a syllabic division) (CVC,CV...) structures. The nonwords were based on real English and Maltese words in order to maintain the appropriate phonotactic rules of the languages. The real words were manipulated in three different ways as depicted in the examples below. Specifically, by altering some or all the vowels in the word, then changing some or all of the consonants in the word, and finally altering both

¹⁶ The dialectal differences were considered in the development of the Maltese-English nonword repetition test, such that no consonantal phonemes or vocalic sounds which are not present in the Maltese phonetic inventory were used.

vowels and consonants. Table 13 outlines how this was done for the English words. Table 14 then gives examples of the nonword development from Maltese words.

Table 11

Development technique of English-based nonwords

	Real word	Phonetic transcription	Change of vowels	of	Change of consonants	of	Change of both vowels and consonants
2-syllable	flipper	/flɪpə/	/fləpɪ/		/grɪkə/		/grəkɪ/
3-syllable	banana	/bʌ'nɑ:nɑ/	/bʌ'nɛ:nɑ/		/gʌ'kɑ:nɑ/		/gʌ'kɛ:nɑ/
4-syllable	demonstration	/dɛmɔnstreɪʃən/	/dɪmænstreɪʃən/		/dɛdɔnstreɪtəl/		/dɪdænstreɪtəl/

Table 12

Development technique of Maltese-based nonwords

	Real word	Phonetic transcription	Translation to English	Change of vowels	of	Change of consonants	of	Change of both vowels and consonants
2-syllable	tieqa	/tɪ:ʔa/	window	/tɑ: ʔi/		/ʔɪ:tɑ/		/ʔɑ:ti/
3-syllable	nucçali	/nʊtʃ:ɑli/	glasses	/nɪtʃ:ulɑ/		/tʃʊl:ɑni/		/tʃɪl:unɑ/
4-syllable	prinjolata	/prɪnjɔlɑtɑ/	(traditional carnival cake)	/prɔnjɪlʊtɑ/		/prɔlwɪtu:lɑ/		/prɪlwɔtɑ:lɑ/

The lists were presented to 20 adults in the spoken form and were asked to rate them on the basis of word-likeness (i.e. how much each nonword resembled a true word in the specified language) using a 5-point Likert scale. A score of '5' meant that the nonword resembled most a real word. This method was similar to the technique used in the Jones et al

(2010) study. The final four lists that were developed, each consisted of 12 low word-like nonwords and 12 high word-like nonwords as they were rated. In light of previous research (Bailey & Hahn, 2001; Firsich et al., 2000; Jones et al., 2010; Hay & Munson, 2001; Pierrehumbert & Beckman, 2004; Treiman et al., 2000), the assumption was made that the nonwords rated as *low* in word likeness were more likely to reflect low-lexicality and low-probability nonwords, and vice-versa for nonwords rated as *high*. In addition, each list consisted of eight 2-syllable words, eight 3-syllable nonwords, and eight 4-syllable nonwords. Out of the 24 nonwords, approximately half of them contained consonant clusters. Figure 7 details the layout of each nonword list. The final four lists were created as follows:

- English nonword repetition in quiet (eNWRT(qu))
- Maltese nonword repetition in quiet (mNWRT(qu))
- English nonword repetition in noise (eNWRT(n))
- Maltese nonword repetition in noise (mNWRT(n))

Tables 15 and 16 delineate the nonword syllabic structure for the English and Maltese lists respectively, including examples of nonwords with their syllabic structure and phonological transcription.

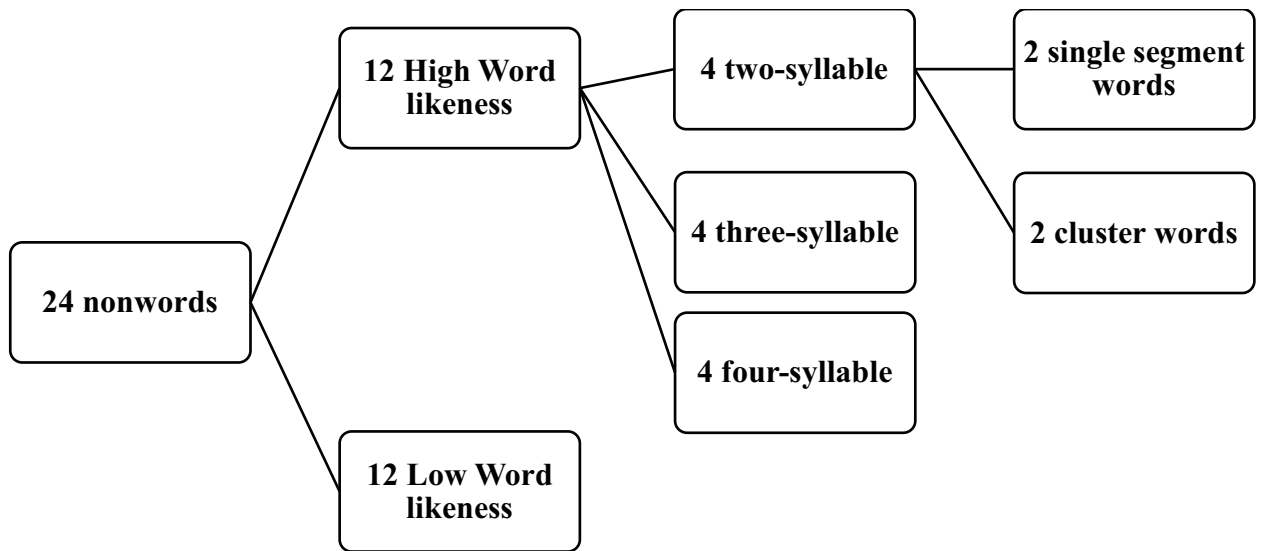


Figure 6 Nonword layout

Table 13

Syllabic structure and examples of the eNVRT

English nonword repetition in quiet (eNVRT(qu)) and in noise (eNVRT(n))						
	Syllabic structure	Examples of nonword	of	Transcription	Number of nonwords (NVRT(qu))	Number of nonwords (NVRT(n))
2- syllable	CVCVC or	‘perben’	or	/pə:bən/	5	3
	CV ‘CVC	‘masheet’		/məʃi:t/		
	CVCCVC	‘pitson’		/pɪts:ən/	0	1
	CCVCV	‘gricker’		/grɪkə/	1	3
	CCVC,CVC	‘plaktuck’		/plæktʌk/	2	0
	CCVCVC	‘blikit’		/blɪkɪt/	0	1
3- syllable	CVCVCV	‘saritor’		/særɪtə/	3	3
	CVCVCVC	‘lamidop’		/ləmɪdɒp/	1	1
	CCVCVCVC	‘stowsiple’		/stoʊsɪpəl/	3	2
	CCVCVCCV	‘trailigra’		/traɪlɪgrɑ/	0	1
	CCVC,CVC,CV	‘trimpampay’		/trɪmpæmpɛɪ/	1	0
	VC,CV,CVC	‘uttripes’		/ʌtrɪpəs/	0	1
4- syllable	CVCVCVCVC	‘jaterbadon’		/dʒætəbædən/	1	1
	CCV,CVCVCVC	‘promifites’		/prɒ'mɪfɪtəs/	2	1
	CVC,CVCVCV	‘niskasery’		/nɪs'kɒsəri/	0	2
	CVC,CV,CCVCV	‘conkidiuder’		/kɒŋkɪdju:dər/	1	0
	CVC,CV,CCV,CVC	‘cumpidjugel’		/kʌmpɪdju:gəl/	0	1
	CVCV,CCCVCV	‘gonerstraitor’		/gɒnə'streɪtər/	0	1
	CVCVC,CCCVCVC	‘didanstraitel’		/dɪdænstreɪtəl/	0	1
	VC,CVCVCVC	‘impigaitel’		/ɪmpɪgeɪtəl/	1	0
	VC,CVCVCV	‘elpibaitor’		/ɛlpɪbeɪtə/	1	1
	VCV,CCVCVC	‘eterplishen’		/ɛtə'plɪʃən/	2	0

Table 14

Syllabic structure and examples of the mNVRT

Maltese nonword repetition in quiet (mNVRT(qu)) and in noise (mNVRT(n))					
	Syllabic structure	Examples of nonword	Transcription	Number of words (NVRT(qu))	Number of words (NVRT(n))
2- syllable	CVCV	‘qieta’	/ʔi:ta/	0	2
	CVCVC	or ‘reġal’	/rɛ:dʒal/	2	1
	CV’CVC	or ‘xiħax’	or /ʃiħa:f/		
	CCVC,CV	‘klissa’	/klɪs:a/	2	2
	CVC,CVC	‘quttas’	/ʔʊt:as/	2	2
	CCVCV	‘xkuta’	/ʃku:ta/	1	1
	CVCVCC	‘liranċ’	/lɪrɔntʃ/	1	1
3- syllable	CVCV’CVC	‘karewatt’	/kɔrɛ'wat:/	2	0
	CVCVC,CV	‘vetoċċi’	/vɛtɔʃi:/	0	1
	CVC,CVCV	‘niċċula’	/niʃ:ula/	2	2
	CCVCVCCV	‘prefedju’	/prɛfɛ:dju/	1	1
	CCV,CCVC,CV	‘stetwatti’	/stɛtwat:i/	1	1
	CVCV’CVCC	‘bexurink’	/bɛʃurɪnk/	1	1
	CCVCVC’CVC	‘trokabbum’	/trɔkɔ'b:u:m/	1	1
4- syllable	CVCVCVCV	‘kolemati’	/kɔlɛmatɪ/	2	2
	CVC,CVCVCV	‘revvofija’	/rɛv:ɔfija/	1	2
	CVC,CVCVC,CV	‘duzzjanorji’	/dʊʃjɔnɔrʒi/	1	0
	CCVCVC,CVCV	‘stitagġemu’	/stɪtag:ɛmu/	1	2
	CCVC,CVCVC,CV	‘trispuronta’	/trɪspʊrɔntɔ/	1	0

CCVC,CVCVCV	‘pronjiluta’	/prɔnjɪlu:ta/	1	1
CVCVCV’CVCC	‘talefunest’	/talɛfu'nɛst/	1	1

Each list was then audio recorded and the nonwords transferred onto a computer. Two lists (the English and Maltese nonword repetition) were saved in wav. format in order to then be presented through an audiometer. The English and Maltese nonword repetition in noise lists were further manipulated. Multi-speaker speech babble was added to the audio file to be presented at 5dB less than the nonwords. This was done using EarMix software (MK Prosopsis Ltd).

3.6.2.2 Administration and scoring of the nonword repetition tasks. Two lists per session were presented through an Interacoustics diagnostic two-channel audiometer (AC 33) via TDH39 supra aural headphones. The first list presented was one NWRT(qu), while the second list was a NWRT(n) based on the other language. Each of the subject’s responses were audio recorded and transcribed.

Each list included 24 items. The first 12 items were presented through one ear, while the rest of the items were presented through the other ear. Approximately half the children listened to the first 12 items through their right ear. The other half initiated the listening task using their left ear. In the first session the choice of which NWRT(qu) that was to be used (Maltese or English-based) depended on the subject’s most comfortable language. Therefore, if the child used Maltese as their primary language then the first NWRT(qu) was presented using the Maltese-based nonwords. The NWRT(n) was then presented using the list from the subject’s second language. So if the child’s primary language was Maltese, the NWRT(n) was presented using the English-based nonwords. The reason for this choice was due to the fact that since the NWRT(qu) and NWRT(n) based on one language occasionally used similar nonwords (possibly stemming from the same real word), a subject could

remember nonwords from the first list still fresh in his/her mind, and repeat the same nonword when listening to a similar nonword in the second list. This would result in an error that possibly could have been avoided. In the second session the two remaining NWRTs were presented.

The four lists were analysed in terms of the percentage errors. The subjects' responses were phonetically transcribed, the amount of errors brought out and calculated as a percentage of the total possible errors for each of the sub-divisions outlined next:

- total percentage error
- percentage error in 2-, 3-, and 4- syllable words
- percentage error in items with consonant clusters
- percentage error in items with consonant sequences
- percentage error in items with single consonants

The transcribed responses were further analysed in terms of the error patterns for each subtest. Error analyses of NWRTs have been reported in the literature. Riches, Loucas, Baird, Charman and Simonoff (2011) classified errors in terms of 'structure-preserving' (where the structure of the word remains unchanged, (CVCC remains as is) and structure-changing types (CVCC becomes CVC). Kapalková, Polišenská and Vicensová (2013) suggested a deeper categorisation of errors in three levels:

- phonological (phoneme): including errors in consonants, vowels and diphthongs;
- syllable: causing changes in the syllable structure (e.g. weak syllable deletion, final vowel deletion, and initial and final consonant deletion);
- word: such as nasal and alveolar assimilation.

Sheer-Cohen, Evans and Coady (as cited in Burke & Coady, 2015) divided error types divided in four main areas:

- Motor errors: including errors in voicing, phoneme switching (metathesis), and assimilation (where a phoneme is substituted with another phoneme which occurs in the syllable)
- Articulatory errors: in which a phoneme is substituted with an earlier acquired phoneme.
- Omission errors: both at the phoneme and syllable level
- Unclassifiable

The error analysis adopted in this study is an amalgamation of the classifications presented in the reported literature, the results of which are reported in chapter 6. The chapter further presents the errors in terms of any phonological error patterns that appear. For the purpose of this project, the phonological error patterns that have been found to emerge in Maltese children will be referred to (as was reported by Grech, 1998; Grech & Dodd, 2008). These include:

- Structural processes: such as weak syllable deletion, syllable initial/final consonant deletion (both in terms of single segment and consonant cluster omissions), consonantal harmony and reduplication, syllable initial reduction, compensatory vowel lengthening, and gemination of a consonant sequence.
- Systemic processes: comprise fronting, backing, stopping, gliding, lateralisation of /r/, affrication / deaffrication, and voicing / devoicing.

The reader is referred to Grech and Dodd (2008) and Grech (1998) for an in-depth analysis of these phonological processes as exhibited by Maltese children.

In cases where the same error was produced most frequently by the participants, an acoustic analysis of the nonword was performed, where the acoustic characteristics of the child-produced nonword were compared with the target one through spectrographic analyses.

A spectrogram is considered to be the gold standard on acoustic phonetics, converting speech into a visual representation (Katz, 2013). It displays information of frequency and amplitude over time. Amplitude is interpreted through the darkness of the output, where the darker the representation the greater the energy. Frequency is represented on the vertical axis and time on the horizontal axis (Hagiwara, 2009). Different speech sounds have been described to encompass a specific representation on the spectrogram (Hagiwara, 2009; Katz, 2013):

- Vowels are recognised through their strong steady formants¹⁷ on the spectrogram.

Figure 8 presents a spectrogram of some vowels found in Maltese and English.

From left to right: [i, ɪ, ε, a, ɔ, ʊ, u].



Figure 7 Spectrogram depicting vowels

- Plosives are characterised by an interval of silence on the spectrogram, as a result of the complete closure of the vocal tract and therefore no resonance. Figure 9¹⁸ below provides a visual representation of the plosives /apa/ and /aba/.

¹⁷ A formant is a representation of the vocal tract resonance in terms of its harmonics and is characterized by a dark horizontal band across time (Hagawara, 2009).

¹⁸ Note: the recordings of the spectrograms in this section were obtained using the same speaker as the NWRTs

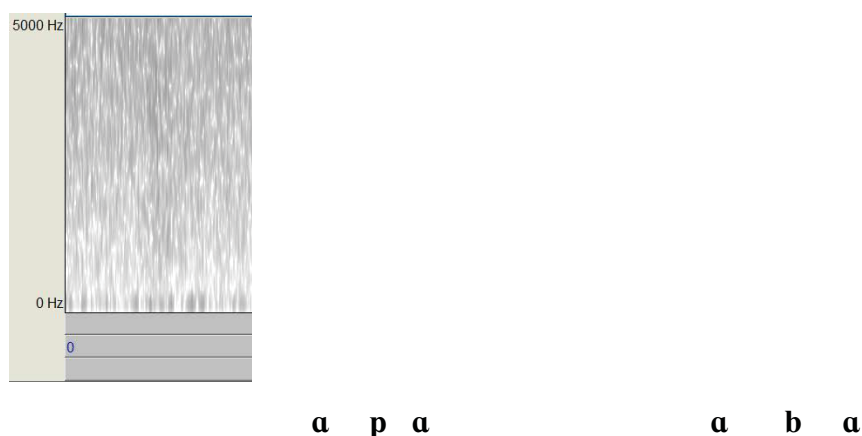


Figure 8 Spectrogram depicting plosives

- Fricatives are produced with a partial obstruction of the vocal tract, causing an amount of noise. Their representation is fairly long in comparison with plosives and the spread of amplitude and frequency varies between fricatives. Figure 10 displays spectrograms of the fricatives /s/, /ʃ/, and /f/. From this spectrogram it is evident that /ʃ/ seems to be produced with the strongest airflow. In addition, the sibilants seem to be produced with more energy at in the high frequencies when compared with the non sibilant sound.

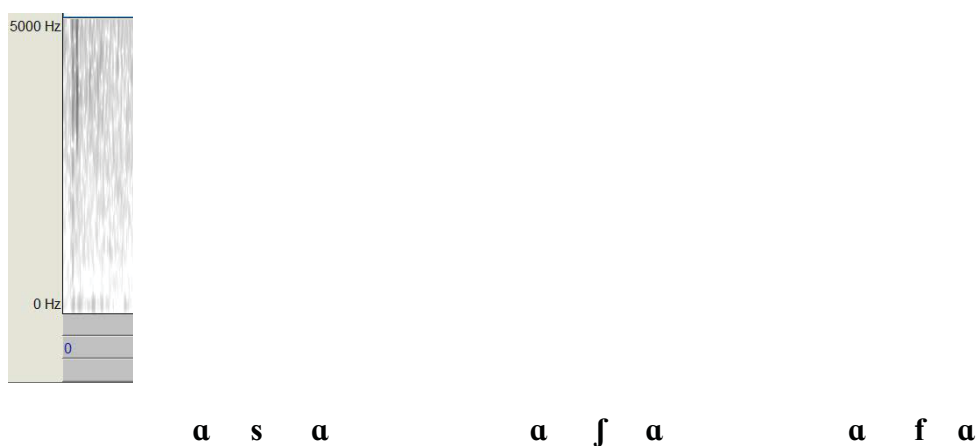
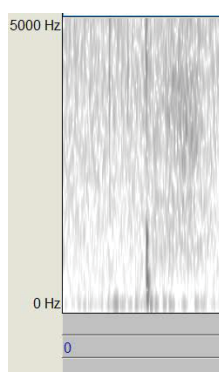


Figure 9 Spectrogram depicting fricatives

- The affricates available in Maltese and English include a voiceless or voiced abrupt alveolar beginning as is found in a plosive, followed by an energy similar to the fricatives, to produce /ts/, /dz/, /tʃ/, and /dʒ/. Examples of affricates are presented in figure 11.



a ts a

a tʃ a

Figure 10 Spectrogram depicting affricates

- Nasal sounds tend to display little energy on the spectrogram, depicted by lighter formants when compared with vowels. Figure 12 shows spectrograms of the syllables /ama/, /ana/, /aŋa/. It can be seen that the alveolar and palatal nasals /n/ and /ŋ/ as produced by the Maltese speaker are slightly higher in frequency than the bilabial nasal /m/. Darker formants are also evident in /m/ indicating the use of more energy to produce it.

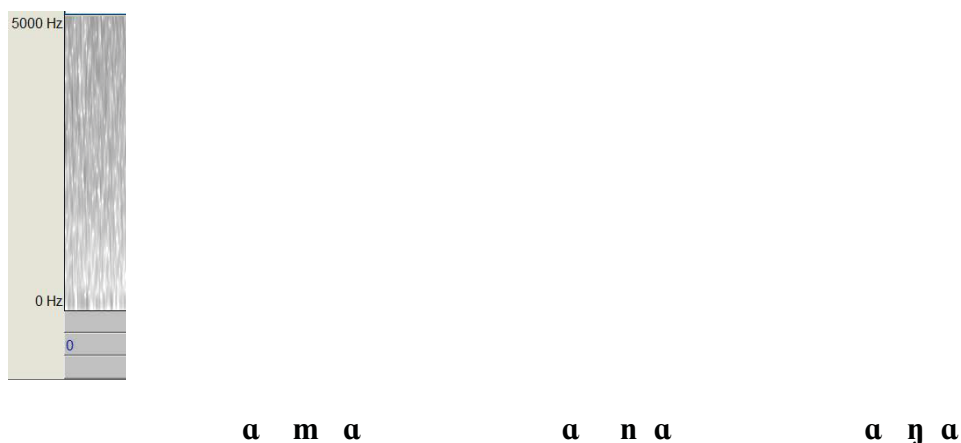


Figure 11 Spectrogram depicting nasals

- Approximants fall under the non-vowel sonorant category. They comprise the glides /w/ and /j/, and the liquids /l/ and /r/. Similar to vowels, approximants are not associated with any form of friction or occlusion in the vocal tract and their spectrograms therefore display formants just like the vowels. Figures 13 and 14 illustrate spectrograms for glides and liquids. The difference between the vowels and approximants is marked by the lower energy demonstrated by the latter.

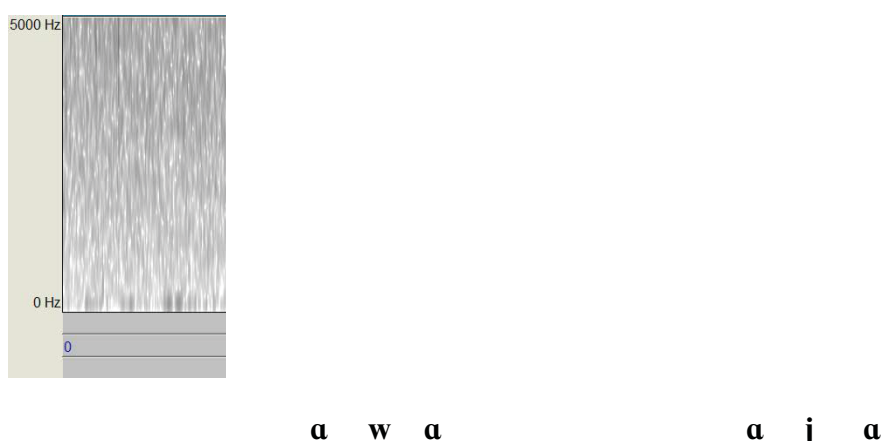
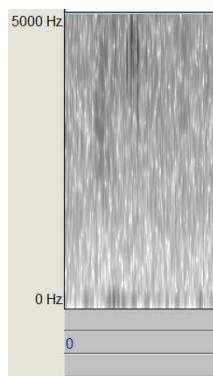


Figure 12 Spectrogram depicting glides



a l a a r a

Figure 13 Spectrogram depicting liquids

3.6.3 The Sentence Imitation Task (Grech, Franklin & Dodd, 2011). The *Sentence Imitation Task (SIT)* is part of a larger assessment of language standardised on bilingual Maltese children, namely the Language Assessment for Maltese Children (LAMC; Grech, Franklin & Dodd, 2011). Sentence imitation is a good indicator and reliable tool for assessing children's language skills (Seeff-Gabriel, Chiat & Dodd, 2010). It is quick to administer and hence a valuable tool as part of an assessment battery of auditory processing, which is quite lengthy overall. With the continuous debate on whether auditory processing disorder can be classified as an entity on its own (Rosen, Cohen, & Vanniasegaram, 2010), or comorbid with other disorders, such as DLD and LitD (Sharma et al., 2009; Ferguson et al., 2011) (as was explained in chapter 2, section 2.12), it is necessary at this stage to include a brief assessment of language processing both for clinical purposes, in order to help the clinician explore further the specific difficulties a child might have, and for purposes of further research, in an attempt to contribute to this debate.

The *SIT* requires the child to repeat 10 sentences of increasing length and complexity. The assessment allows flexibility to present the sentences in both Maltese and English. Previous research studies on Maltese children have used the *SIT*. It has been standardised on Maltese bilingual children aged up to 5;0 years by Grech et al. (2011) in both the Maltese and

English languages and found to correlate well with verbal comprehension abilities. Xuereb (2012) carried out further research using the Maltese version of the *SIT* in children aged approximately between 8;0 and 10;11 years (4th, 5th, and 6th grades at school) adding to the data on TD children.

The scoring procedure throughout this project was carried out in line with authors' (Grech et al., 2011) directions, namely:

- A score of '2' was given if the complete sentence is repeated clearly and correctly;
- A score of '1' was given > 50% of the sentence is repeated, but not 100% correct;
- A score of '0' was given if < 50% of the sentence is repeated;

All responses were further analysed qualitatively in order to investigate the error patterns which emerged through the sentence imitation task. These were classified for:

- a) Inaccurate imitations in three categories: no imitation, grammatically correct response but incorrect imitation, and grammatically inaccurate/incorrect imitation;
- b) Imitation accuracy of: content words (such as nouns, adjectives, verbs, and adverbs), function words (e.g. prepositions, pronouns and determiners), and inflections (such as plural –s, the third-person singular –s, and the past tense –d).

3.7 Auditory processing subtests using no linguistic content

These tests comprised different assessments of temporal processing. Temporal processing skills are necessary in the timing elements of sound, which would in turn allow complex accurate higher level speech perception (such as phonemic, lexical and prosodic distinctions) and the processing of spoken language (Chermak & Musiek, 1997). It further plays a role in other auditory processes including sound localization, discrimination, pattern processing, binaural integration, and binaural separation (Shinn, Chermak, & Musiek, 2009),

as well as understanding speech signals both in quiet and in adverse listening conditions (Strouse, Ashmead, Ohde, & Grantham, 1998).

This study aimed to obtain data on temporal resolution and temporal ordering through three assessments: The Duration Pattern Sequence test (Musiek, 1994), Frequency Pattern test (Musiek & Pinheiro, 1983), and the Gaps-in-Noise test (Musiek, 2003). These are explained next.

3.7.1 Duration Pattern Sequence Test (DPT) (Musiek, 1994). The duration pattern test was administered through TDH39 supraaural headphones via a calibrated Interacoustics Clinical Audiometer AC33 connected to a computer which included the necessary DPT sound file. The recording was obtained from AUDiTEC Inc. The DPT included sequences of three consecutive tones, each of 1000Hz and presented at 50dBHL. The tones differed in duration – being either of long (500ms) or short (250ms) duration and each tone was divided by a 300ms interval. The combination of these two tone durations resulted in six different sequence patterns: Short Short Long, Short Long Short, Long Long Short, Long Short Short, Short Long Long, and Long Short Long.

Each participant was given three practice trials. If they did not understand the concept the trials were repeated once again. Following the trials, a total of 30 items were administered – 15 in each ear. The participants were required to draw the stimulus heard on a tablet provided. Therefore if they heard a long tone they would be required to draw a long line ‘-----’, while if they hear a short tone they would be required to draw a dot ‘•’. For example, the sequence *long, long, short* would require the drawn response of ‘----- •-----’.

-’. The number of correct responses was counted in order to obtain the percentage correct score.

3.7.2 Frequency Pattern Sequence Test (FPT) (Musiek & Pinheiro, 1987). The FPS is a similar test to the DPS and administered in a similar way. The difference with this test is that instead of long and short tones, high frequency (1122 Hz) and low frequency (880 Hz) tones presented, also in a sequence of three, generating six different sequence patterns: High High Low, High Low High, Low Low High, Low High High, High Low Low, and Low High Low. The participants were asked to hum each series. Once again the number of correct responses was considered and the percentage accuracy was obtained.

3.7.3 Gaps-in-noise Test (GIN) (Musiek, 2003). The GIN test stimuli was also obtained on a compact disc through AUDiTEC Inc and played through a clinical audiometer in the same manner as the DPT and FPT. The test comprises between 28 and 36 sections of a 6-second computer generated broadband noise. Each section contains between zero and three silent intervals (gaps). The duration of each gap varies between 2 and 20ms through an array of ten gap interval times: 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20ms. Each list of noise segments included randomized gaps in relation with the number of gaps, and the occurrence of the gap duration and gap location. In this way, the probability of guessing the correct answer is reduced (Musiek et al., 2005; Shinn et al., 2009). Figure 15 shows an example of the GIN spectral and time display of a noise segment (A) and three segment examples with different gap configurations (B). This figure is taken from Shinn et al. (2009).

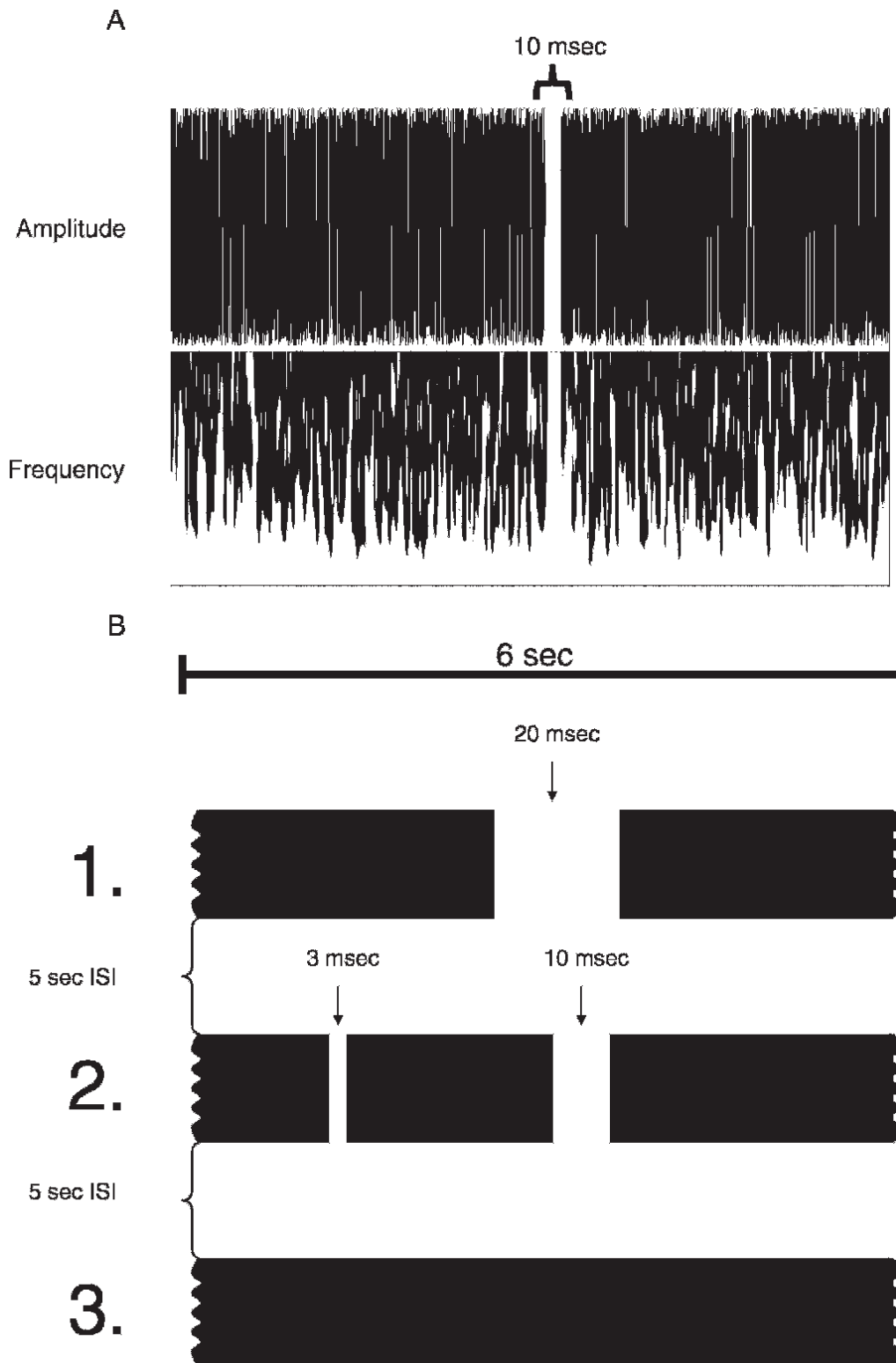


Figure 14 A) Spectral and time display of noise with a 10ms gap. B) Examples of GIN segments showing the stimuli duration, inter-stimulus intervals, and a number of gaps of various durations. From Shinn et al. (2009).

The GIN consists of four different lists, each with 60 gaps. As was previously stated (section 3.2.3.4), the lists are of equivalent difficulty and demonstrate no significant

differences across the lists for both ears (Musiek et al., 2005). The researcher opted to use two lists – one per ear, which were presented interchangeably. Approximately half of the children listened to one list through their right ear, while the other half listened to the same list through their left ear. Furthermore, half of the children started the assessment listening through their right ear, while the other half started it listening through their left.

Prior to the commencement of the test all subjects were provided with three practice items. If some participants could not grasp the concept using these three, they were given the opportunity to listen to them again to ensure that they had understood the task. As was described in the pilot study, the participants were required to count the noise segments (rather than the gaps). So if one six-second noise segment included 3 gaps, the participants were required to give the answer ‘four’. If not all the gaps in a segment were identified it was assumed that the gaps of smallest duration was not perceived when scoring. So if, for example, a noise segment consisted of three gaps of 20, 6, and 3ms and the child identifies two gaps, it was noted that the gaps identified were of 20 and 6ms and therefore the gap of least duration is not identified.

The results were scored in two ways:

1. For each ear, the shortest gap duration for which each participant correctly identified 4 out of 6 times was recorded (Ath) (Musiek et al., 2005). However, it was required that this level of performance was either maintained or improved as the duration of the gaps increased.
2. The percentage correct responses out of the total number of gaps presented per ear was calculated, followed by the total percentage correct for both ears.

3.8 Conclusion

This chapter concentrated on providing a description of the methodology used for this research. In parallel with the development and completion of this chapter was the data collection phase. With this complete, the consecutive phase was to carry out a statistical analysis of the data. This is provided in the following chapters (Chapter 4: *Reliability and Validity of the tool*; Chapter 5: *Quantitative results*; Chapter 6: *Qualitative results*), where the strength of the assessment battery and performance of the subjects on the subtests is illustrated and explained.

The reader is reminded that the aim of this study is to investigate the performance of Maltese children on different subtests of AP. In addition to the audiometric screening tests, each child completed a total of 10 subtests:

1. Four speech based tests: DDTs (free recall and simple focussed attention), Maltese- and English-based nonword repetition task in noise
2. Three non-speech based tests: DPT, FPT, and GIN.
3. Three tests of language processing: Maltese- and English-based nonword repetition task in quiet, and the SIT.

Chapter 4. Reliability and validity of the assessment protocol

4.0 Chapter overview

Evaluating the reliability and validity of an assessment or questionnaire provides important information with regard to the consistency of the tool and whether it is actually measuring the targeted task/s (Howell et al., 2012). This chapter discusses the reliability and validity of the subtests in the assessment battery. The reader is provided with an evaluation of the methods of reliability and validity available, followed by an explanation of the methods used for this tool. For the purpose of this chapter the subtests have been grouped into three sections in which their validity and reliability are discussed separately. These include:

1. The tools that were newly developed by the researcher,
2. The developed and established tools which were modified for this study,
3. The previously established tools which were unaltered for this study.

4.1 Reliability and validity testing

4.1.1 Reliability. The term reliability can be defined as the stability or consistency of results when taken over time or across raters (Patel & Joseph, 2016). In other words it is the extent to which tool produces the same result when repeated. Low reliability implies that the scores obtained include considerable measurement error (Warner, 2012). For example, low test-retest reliability occurs when discrepancies in the measurement will take place upon retesting, resulting in a difficulty to meaningfully interpret the assessment outcomes (Downing, 2004; Kaplan & Sacuzzo, 2017).

When measuring the reliability of a tool the correlation coefficients are of prime importance. The correlation coefficient determines the amount of agreement between the two sets of scores, ranging between -1 and +1. The closer the coefficient is to +1 the higher the

correlation, i.e. the better the agreement (Kline, 2013). Correlations could be both positive (indicating a direct relationship), or negative correlations (portraying an inverse relationship). Generally, a measure is taken to be reliable when it has a positive correlation coefficient of around .80 or higher (Jackson, 2014; Kline, 2013). However, coefficients can be described as **strong** when the coefficient is between .70 and 1.00, **moderate** when it is between .30 and .69, and **weak** when it is between .00 and .29. (Jackson, 2014).

Reliability is estimated by assessing three main characteristics of a tool; namely its **stability, equivalence** and **internal consistency** (Barker, Pistrang, & Elliott, 2002; Drost, 2011). The stability of the tool is measured by analysing its **test-retest reliability** (Rubin & Ballamy, 2012). This is based on how the results of an assessment tool correlate when administering it two or more times (Dawson, 2002). This reliability method can be subjected to some limitations, mainly related to the selected time frame between the first and second test. If the interval between the two tests is too short, then the subjects could remember what was presented the first time, resulting in the second test being affected by a memory factor (Drost, 2011). On the other hand, if the interval is too long, the re-test results could be affected due to maturation, changes in the subject's ability, feelings or attitudes, and outside influences or situational factors (Drost, 2011).

Equivalence refers to the extent to which two more instruments or items agree when measuring the same concepts, at the same level of difficulty at approximately the same point in time (Patel & Joseph, 2015). **Equivalence reliability** is assessed through a method known as *parallel forms*, where two sets of the same measure are administered to either the same or different groups, and their results related to bring out the degree of association between them, i.e. the strength of correlation (Laerd dissertations, 2012). The greater the correlation between them, the more equivalent the two instruments are. In practice, this procedure is not often employed, due to the difficulty in verifying that two tests are truly parallel (Bolarinwa, 2015).

Internal consistency analyses the reliability of the test constituents. It measures the correlation between different items that propose to evaluate a similar general construct within the same tool (Drost, 2011). In other words it explains the extent with which the items in a measurement are inter-related (Tavakol & Dennick, 2011). The most broadly used method of analysing the internal consistency in the behavioural sciences is coefficient alpha (Drost, 2011), a statistic calculated through the correlations between items. Internal consistency scales from negative infinity to one, with the negative coefficient alpha occurring whenever there is pronounced within-subject variability on the items measuring the same concept (Knapp, 1991). This often indicates that either the tool items have little in common or the test is not long enough (Drost, 2011). Another measure of internal consistency is the **split-half reliability** method. Through this method all items are split into two equal sets of items (Groth-Marnat, 2009). The scores obtained from these sets are then correlated. Some limitations to this method are evident. First is the fact that half the measures are used, resulting in an underestimation of the correlation. However, the Spearman-Brown prophecy formula is used to overcome this limitation (Acock, 2008). Another limitation is that depending on how the items are split would result in a different correlation outcome (the choice of correlating the first half with the second half of items on the questionnaire; or odd versus even items). It has been suggested that a random selection might be the best way of choosing the items in each set to be correlated (Acock, 2008).

4.1.2 Validity testing. The term *validity* refers to the degree which a tool accurately assesses what it is meant to assess (Dawson, 2002) – that the outcome of the measurement parallels the real situation in the world (McBurney & White, 2009). Despite the relation between reliability and validity of a measurement it is crucial to point out that the reliability and validity are not one and the same thing. A reliable measurement does not necessarily need to be valid, in that a measurement can give consistent results but not be

measuring what it really aims to measure (Clark, Golder & Golder, 2012). Validity coefficients are not interpreted in the same way as reliability coefficients. While it is important for a reliability coefficient to be .70 and above to be considered as strong, the strength of validity coefficients is determined by its **statistical significance**. Therefore, a low coefficient of .30 could still be valid if it is found to be statistically significant at the .05 or .01 level (Jackson, 2014).

Early theories have classified validity into two main types: internal and external validity (Campbell & Stanley, 1963). More recently, it has been proposed that validity is divided into four types: statistical conclusion validity, internal validity, external validity, and construct validity (Drost, 2011).

Statistical conclusion validity analyses whether there is a relationship between two variables. It refers to deductions about whether it is acceptable to assume co-variation with a given specified alpha level and the discrepancies attained (Cook & Campbell, 1979).

Statistical conclusion validity is not concerned with what causes the relationship between variables, but simply whether there is any relationship, irrespective of it being causal or not (Adams, 2008). For the purpose of this research it is of interest to deduce the relationship strength between the independent variable '*pathology*' and each of the subtests (dependent variables).

Internal validity refers to the *essence* of what the tool is aiming to measure. It analyses the causality in a relationship between an independent and dependent variable (Leighton, 2008) and aims to answer the question: did the independent variable trigger the dependent variable to change? (Giannatasio, 2007).

External validity refers to the degree with which the results obtained by the tool can be generalized from the test sample to a target population (Leighton, 2008). The

generalisation to a specific target population must be distinguished from generalising across different populations (Drost, 2011). In this study, investigations were carried out on Maltese children within a specific age range. So if a relation is found between a measurement and this specific sample of a population, one cannot conclude that the same relation will be present across other populations (Cook & Campbell, 1979).

Construct validity assesses the ability of a tool to measure the trait for which it was intended (Leighton, 2008). It analyses the efficiency of how a concept or idea (the construct) has been translated into actual functioning (Trochim, 2006). Trochim (2006) classifies construct validity into two sorts: *translation validity* and *criterion-related validity*.

Translation validity aims at examining the extent to which theoretical constructs are correctly translated into operational function by means of subjective judgment and analysis of the content (Drost, 2011). This is executed through *face validity* and *content validity* respectively. **Face validity** is the simplest way of measuring validity as it is mainly based on judgment (Dawson, 2002). It analyses whether the tool measures what the researcher expects it to measure. By itself it is not sufficient to establish the validity of a tool (Giannatasio, 2007) and must be backed up through another form of validity. **Content validity** refers to the appropriateness in the content of a measurement tool (Leighton, 2008). It concerns the extent with which the tool fully measures the subject of interest (Miller, 2008) and uses a qualitative means of ensuring that the items included in the tool extract the meaning of a concept delineated by the researcher (Drost, 2011). A content valid tool is usually developed through its rational analysis by raters who typically understand the subject of interest. Through feedback from these raters regarding the clarity and comprehensiveness of the tool it would be decided which items should be included in the final measurement instrument (Miller, 2008). Content validity of this assessment battery was attempted through a review of

the literature (see section 2.4) pertaining to recommended approaches and protocols, despite the lack of a 'gold standard' in APD measurement.

The **criterion related validity** measure examines the extent at which a test measure correlates with one or more external referents (Drost, 2011), such as another tool. Ideally, the instrument with which the tool is being correlated is already established and used to measure the same variable (Barker, Pistrang & Elliott, 2002). Criterion-related validity is further subdivided into **convergent** and **discriminant validity** – The former assesses the notion that the same theory measured in different ways produces similar results. To assess for convergent validity, two different tests are used. Discriminant validity, on the other hand, analyses the evidence that the measured construct can be distinguished from other constructs, resulting in low correlations between the two measures (Shah, n.d).

Concurrent and Predictive validity – Concurrent validity applies when a research tool has a high correlation with an established measurement tool (Wood & Ross-Kerr, 2010). Ideally, the concurrent validity coefficient should be above 0.75 (Shrock & Coscarelli, 2008). The predictive validity of a tool refers to its ability to measure some event or outcome in the future (Drost, 2011). This form of validity is determined through measurement of the trait in the present, followed by a wait to investigate whether the event occurs as was predicted (Wood & Ross-Kerr, 2010). Concurrent validity was investigated for the developed tools of the assessment battery. The outcome of which is detailed in sections 4.2.1.5 (QCAP) and 4.2.2.5 (NWRTs).

4.1.3 Reliability and validity of auditory processing tasks. Within the area of auditory processing there seems to be a lack in validity and reliability testing of the behavioural tests as well as questionnaires (DeBonis, 2015). Although there are various auditory processing tests available to clinicians, many do not provide information about

validity and reliability (Dawes & Bishop, 2009; Keith, 2009). This gap could stem from the lack of consensus with regard to exactly what concept needs to be measured (de Wit et al., 2016). In the development of the SCAN-C test for auditory processing disorders in children, Keith (2000) provided normative data and results on test-retest reliability and concurrent validity for all subtests within the battery on American children aged between 5;0 years and 11;11 years. Mukari, Keith, Tharpe and Johnson (2006) developed a dichotic digit test in the Malay language. Similarly to Keith (2000), the authors report normative values and test-retest reliability results. However, no validity testing was mentioned. Test-retest reliability measures were also reported for a battery of auditory processing tests on Portuguese speakers (Frasca, Lobo, & Schochat, 2011). Locally, there have been a few small-scale studies investigating the reliability and validity of auditory processing tests. Gabriele (2017) reports reliability and validity outcomes on an array of speech in quiet and in noise tests (including the ones used in this study) for young Maltese adults. Gabriele's study incorporated three reliability measures: test-retest, inter-rater, and intra-rater reliability, as well as construct and concurrent validity. Another local study examined the reliability of temporal ordering and temporal resolution in Maltese children aged between 7;00 and 9;11 years (Hales, 2016). This study reported test-retest and inter-list reliability outcomes.

In an attempt to develop a robust assessment tool for the Maltese paediatric population, the next sections present and discuss reliability and validity outcomes for the tests used within the battery.

4.2 Reliability and validity of the developed tools

The tests developed by the researcher included:

The Questionnaire of (Central) Auditory Processing

Test of Maltese Nonword Repetition

Test of English Nonword Repetition

Test of Maltese Nonword Repetition in Noise

Test of English Nonword Repetition in Noise

Approximately 10% of the sample, including 10 typically developing subjects and 2 subjects that were part of the clinical sample, were selected via snowball sampling to undergo measures of reliability and validity. Testing of these subjects was completed by five research assistants (RAs); four of which being Speech-Language Pathology graduates and one psychology graduate. All received a three-hour training session on administration and scoring of the assessments by the researcher. Following which they underwent a practice session in which they were able to administer the tests on each other and become familiar with the audiometric settings for each subtest. Throughout the actual testing period of two months (July-August, 2014) the RAs kept in contact with the researcher and were given support mainly through electronic means.

4.2.1 The Questionnaire of (Central) Auditory Processing (QCAP).

4.2.1.2 *Internal Consistency and Split Half Reliability of the QCAP.* In order to determine the internal consistency and split-half reliability of the QCAP the Cronbach's alpha (α) and the Spearman-Brown prophecy formula were used respectively. A total of 130 questionnaires were included in this analysis. Table 17 shows the inter-item correlations obtained while table 18 provides the split-half reliability of the measure.

Table 17

Inter-item correlations of reliability of the QCAP

Cronbach Alpha	Cronbach Alpha Based on Standardized Items	Number of Items
.921	.922	20

Table 18

Split half reliability estimates for the QCAP

Cronbach Alpha	Part 1	Value	.858**
		N of Items	10
	Part 2	Value	.868**
		N of Items	10
		Total N of Items	20
Correlation Between Forms			.793**
Spearman-Brown Coefficient	Equal Length		.884**
	Unequal Length		.884**
Guttman Split-Half Coefficient			.884**

** . Correlation is significant at the 0.01 level (2-tailed).

The Cronbach's Alpha exhibited the correlations between the items. The closer the coefficient is to 1 the stronger the inter-relation between items. The results demonstrate that the items used to form the QCAP prove to be measures of strong reliability in terms of internal consistency with Cronbach's alpha being above .90 and Guttman Split-Half Coefficient above .80.

4.2.1.3 Test Retest reliability. The parents / carers of 12 participants were asked to complete the Questionnaire of (Central) Auditory Processing at the initial assessment date and again following a two week interval. This time frame between test and retest has been recommended as adequate (Sims, 2000), with a further recommendation that a month is not exceeded (Barker et al., 2002). Recent literature has also mentioned a gap of three months between the test and retest sessions (Kline, 2013). However, Kline (2013) also points out that if children are the subjects used in the study this could result in a low correlation between tests due to the developmental changes of the children, and the different rates at which children develop. The subjects to undergo this measure were recruited through snowball sampling. The background information of these subjects is tabulated below (Table

19). Overall, the sample used for further reliability testing is representative of the total sample obtained, with the exception of the primary language. While in the entire sample it was found that more children used Maltese as their primary language, in this sample more children preferred English. This difference is possibly due to the sampling methods: random versus snowball sampling in the data collection of the entire sample and that used for reliability testing, respectively.

Table 19

Participant Characteristics

	Age			Primary Language		Location		School		
	7;00 - 7;11	8;00 - 8;11	9;00 - 9;11	Maltese	English	North	South	Govt.	Church	Inde.
Number of children	4	4	4	5	7	10	2	6	4	2

In order to assess the test-retest reliability of the questionnaire the total scores obtained on the two occasions were correlated.

Since the analysed data are continuous, the test-retest reliability measure of the questionnaire total score was calculated using the Spearman correlation (Chok, 2010) as shown in table 20. In order for the test to be reliable, the scores obtained from the questionnaire on the first administration should be similar to scores obtained from the second. Furthermore, the recommended test retest reliability coefficient is of .80 or higher for these statistics to be suggestive of suitable test re-test reliability (Kline, 2000).

Table 20

Test-retest with Spearman correlations

	Total Score 1	Total Score 2
Total Score 1 Spearman Correlation	1	.940**
Sig. (2-tailed)		.000
N	12	12

** . Correlation is significant at the 0.01 level (2-tailed).

The results showed a positive and high correlation between the results obtained on the two occasions, indicating that the questionnaire outcomes should not change significantly over a specific amount of time between administrations.

4.2.1.4 Parallel form reliability. The aim of the QCAP is to analyse the parental perceptions of their child on a number of behaviours and skills related to the auditory processing modality. In order to obtain parallel form reliability, the carers of 17 participants were requested to complete both the QCAP and an already established questionnaire developed to assess auditory processing skills: the Children's Auditory Processing Performance Scale (CHAPPS; Smoski, Brunt, & Tannahill, 1998).

There exist various screening questionnaires with the three most commonly used mentioned being the CHAPPS, the Screening Instrument for Targeting Educational Risk (SIFTER; Anderson, 1989), and Fisher's Auditory Problems Checklist (FAPC; Fisher, 1976) (Emanuel, 2002). These types of questionnaires have the advantage that they are easy to administer, are cost effective, and gather various details that can be provided by different people such as parents and teachers. The disadvantage on the other hand consists of the biases of the individuals filling out the questionnaire (Schow, Seikel, Musiek & Chermak 2007). They could also be misleading or unclear at times; and if too long, could result in fatigue or

lack of interest, which could in turn produce inaccurate information (Wilson et al., 2011). In addition, one cannot exclude the fact that the behavioural characteristics of children with APD overlap with those of children having language and learning difficulties (ASHA, 2005).

Various studies have examined the relationship between the screening tools and APD assessments: Wilson et al., (2011) found weak to moderate correlations between the CHAPPS, SIFTER and the Test of Auditory Perceptual Skills—Revised (TAPS–R; Gardner, 1997) screening tools and diagnostic APD assessments, even when the tools were expected to assess similar auditory skills. The authors also found weak correlations between two screening tests (CHAPPS and SIFTER) indicating that these two tests are screening different sets of skills to a certain extent. These results were consistent with those obtained from previous studies such as Drake et al. (2006) and Lam and Sanchez (2007) who both reported no relationship between screening questionnaires and the diagnosis of APD. Drake et al. (2006) analysed the total score on the CHAPPS in 40 children diagnosed with APD and found no relationship between the two. A similar finding was obtained in a study carried out by Lam and Sanchez (2007). Fisher’s checklist has been criticised, on the grounds that it includes a wide range of characteristics with only a small amount linked to listening (Smoski, Brunt & Tannahill, 1992). Likewise, the SIFTER has been criticised for not being developed specifically to detect the possibility of APD, but rather more general learning difficulties (Wilson et al., 2011). It has therefore been recommended that questionnaires are not used as a screening tool for APD but rather as a way of bringing out any salient behavioural characteristics in addition to the outcomes of an APD assessment (Wilson et al., 2011).

Despite the pitfalls evident in APD screening questionnaires in general, the CHAPPS seems to be a widely used screening questionnaire of auditory processing. In a survey carried out by Emanuel (2002) and Emanuel, Ficca, and Korczak (2011) it was found that 75% of audiologists use questionnaires as an initial screening of auditory processing skills, out of

which a high percentage tend to use the CHAPPS (43% reported by Emanuel (2002) and 51% reported by Emanuel et al. (2011)). The CHAPPS consists of 36 items all related to a child's listening skills. The individual filling in this questionnaire scores each item through a seven-point Likert scale and is required to compare the child's listening behaviour with other children of the same age in relation to quiet, noisy, and ideal situations, auditory memory and attention span, and multiple input situations.

An attempt to measure Equivalence reliability for the QCAP was made in this study. The carers of 10 typically developing children and 7 children with reported diagnosed difficulties including global developmental delay, language and literacy difficulties, learning difficulties and ADHD were given both the QCAP and the CHAPPS. The researcher carried out this step as a means of analysing the reliability of the new questionnaire with an already established questionnaire found to conceptualise behavioural findings related to APD. In light of the previous findings related to screening questionnaires the researcher has opted to devise this tool as an aid to highlight auditory behavioural concerns in Maltese children and NOT as a screening tool of APD.

The Spearman correlation was administered to investigate relations between the total scores in the QCAP and the CHAPPS. It was expected that a negative correlation would emerge since the scoring methods of the two questionnaires were inverse to each other (through the QCAP – the higher the score the greater the difficulties in auditory skills, as reported by the carer. Conversely, in the CHAPPS – the lower the score the greater the difficulties in auditory skills).

Table 20 shows the correlation results for the two questionnaires, while figure 16 provides a graphical illustration. A moderate and (as expected) negative correlation was obtained which was statistically significant at the .05 level. This result was satisfactory,

considering the limitation in obtaining equivalence reliability through parallel forms due to the difficulty in finding two assessments to investigate the same behaviour (Miller, 2008).

Table 21

Correlation between the QCAP and the CHAPPS

		CHAPPS	QCAP
CHAPPS	Spearman Correlation	1	-.401*
	Sig. (2-tailed)		.028
	N	30	30

*. Correlation is significant at the 0.05 level (2-tailed).

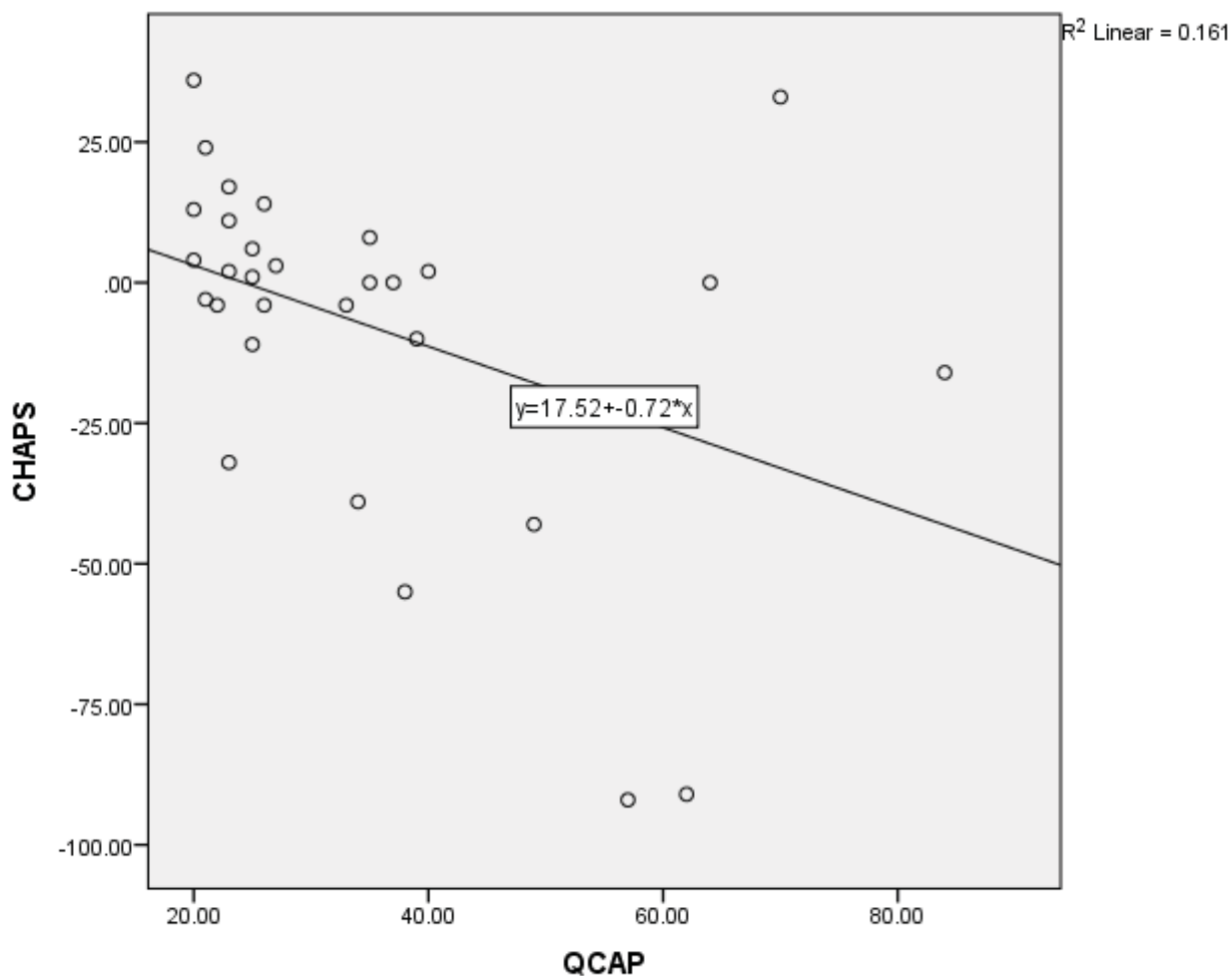


Figure 16 Correlation between the QCAP and the CHAPPS

4.2.1.5 Convergent and concurrent validity. Both these measures of validity are concerned with the strength of correlation and statistical significance between the tool under research and an established tool. As was shown in table 21 above, a statistically significant ($p=.028$) moderate correlation was obtained between the QCAP and the CHAPPS indicating that auditory skills and behaviour measured through parental report yielded rather similar results.

4.2.1.6 Statistical Conclusion and Internal Validity. Of interest to this research was to investigate whether there was a relationship present between the QCAP total

questionnaire score and the independent variables. As will be shown in section 5.3.1, the results demonstrate a statistically significant (at the .01 level) difference between the questionnaire and the *pathology* variable (typically developing sample versus the clinical sample). From this result it can be deduced that there exists a relationship between the dependent (QCAP) and the independent (Pathology) variables, confirming statistical conclusion validity. It can further be deduced that the relationship is causal: the difficulties in the clinical group taking part in this study caused the parents to score significantly different, verifying internal validity.

4.2.1.7 ***Content validity.*** The tool was investigated for content validity to ensure its ability to represent all constructs related to auditory skills. Content validity is determined by expert opinion, which in turn is formulated through research carried out. The questions posed were based on results put forward by Rosenberg (1998). For the purposes of obtaining increased content validity, a review of the literature was also carried out to further back up the statements included in the questionnaire. The statements were grouped under four sections as shown in table 22; *auditory attention, auditory memory, listening in adverse environments, and related behaviour.*

Table 22

Content validity of the statements included in the QCAP

Auditory Skill	Statement	Rationale
Auditory attention	The child finds difficulty in dividing his/her attention.	Iliadou and Bamiou (2012): Children diagnosed with APD performed significantly lower on the CHAPPS <i>Attention</i> scale. Significant moderate-to-strong correlations were found between Dichotic Digits, Duration Pattern tests, and the CHAPPS <i>Attention</i> score. Moore, Ferguson, Edmondson-Jones et al. (2010): Attention and cognitive scores were the best predictors of skills related to auditory processing such as listening and understanding speech-in-noise skills.
	The child finds difficulty in following long conversations.	
	The child finds difficulty in attending to a task.	
	The child is easily distracted.	
	In conversation, the child often asks people to repeat themselves.	
Auditory memory	The child finds difficulty in following directions with multiple steps.	Scheich, Brechmanna, Broscha, Budingera, Ohla, Selezneva, et al. (2011): There exists a link between auditory plasticity, behavioural learning, and associative memory characteristics, where learning comprises several arrays of sound representations in the auditory cortex. Umat, Mukari, Ezan & Din (2011): The co-morbid attention difficulties could affect short term auditory memory.
	The child can be forgetful. Specifically for spoken information.	
	The child finds difficulty in taking notes in class.	
Listening in adverse environments ¹⁹	The child gets distracted in noisy places.	Rosen, Cohen & Vanniasegaram (2010): the most frequently reported difficulties in children suspected of APD were that of listening to the television, and speech in a noisy background. This related to statistically significant poor performance in the speech in noise task in these children when compared to a control group ($p < .001$) Lagacé, Jutras, & Gagné (2010):
	The child finds his/her telephone conversations frustrating.	
	The child finds difficulty in following and/or understanding TV programs.	
	The child tends to shy away from class discussions.	
	The child tends to increase the	

¹⁹

Adverse listening environments – such as noise and degraded signals

	<p>volume of television or audio equipment when listening.</p>	<p>Speech perception in degraded listening conditions is the most frequently reported characteristic of individuals with APD. It depends on both high-level mechanisms (such as language and cognition) and low-level mechanisms (specifically auditory perception). As a result populations identified with language difficulties and those diagnosed with auditory disorders often demonstrate similar difficulties of speech perception in noise.</p>
<p>Related behaviour²⁰</p>	<p>The child finds difficulty listening to speech and understanding it.</p> <p>The child is sensitive to loud sounds.</p> <p>The child seems to be a restless person, who finds great difficulty in keeping still.</p> <p>The child prefers solitary activities to social activities.</p> <p>The child often finds him/herself unable to keep to task deadlines.</p> <p>The child has organisational difficulties that cause problems.</p>	<p>Moore (2011): Found modest but highly significant correlations between auditory processing measures (e.g., backward masking, tone in-noise masking, and frequency discrimination), a range of cognitive measures (e.g., language, literacy, nonverbal IQ and working memory), and speech-in-noise perception. In addition, significant correlations were found between auditory processing and caregiver reports of listening and communication skills.</p> <p>Kreisman, John, Kreisman, Hall, and Crandell, (2012): children with APD exhibit increased psychosocial difficulty when compared to children without APD.</p> <p>Smaldino and Crandell (2004): APD would bring about diminished communication function in social situations. This results in negative psychosocial effects; including anxiety, reduced self-esteem, and depression.</p>

²⁰ General child behaviour – such as understanding of speech and language, distractibility, social communication, and organizational skills.

In conversation, the child tends to tilt his/her head towards speakers.

Sharma, Dhamani, Leung, and Carlile (2014): Children with reported listening difficulty in noise performed worse than the control group ($p=.05$) on a psychoacoustic test of localization.

The outcomes of this literature review suggest that all statements can be related to and backed up by research studies, and in turn indicates satisfactory content validity.

4.2.2 The Nonword repetition tests in quiet and in noise. The procedure on how the nonwords were developed was explained the *Methodology* chapter (section 3.6.2). Each of the four nonword repetition lists underwent the following reliability measures:

- Intra-rater reliability
- Inter-rater reliability
- Test-retest reliability
- Equivalence reliability

4.2.2.1 Intra-rater and Inter-rater reliability. Intra-rater reliability is a method of rating self-consistency in scoring. Reproducibility of data is important in clinical assessment to reduce measurement error which can be introduced by an observer (Hayen, Dennis, Finch, 2007). Through this reliability measure scientific investigations would be established on stronger and more solid evidence (Kilem, 2008).

The data from 15 participants were initially transcribed and scored (as described in section 3.6.2.2) while listening to the live responses during the assessment itself. Throughout this assessment the responses were also audio-recorded and were re-transcribed and scored in the same manner at a later stage (approximately 2 years later). In this way the researcher had no way of recalling the children's live responses. Spearman correlations were used to

investigate the degree to which the scores obtained from the live and recorded responses resemble each other quantitatively.

In addition to the importance of measurements being reproducible within a given observer over time, it is salient for them to be repeatable by different raters (Hayen, Dennis, Finch, 2007), resulting in a strong inter-rater reliability. The same audio-recordings were given to another rater to score in order to analyse the inter-rater reliability of the tool. The rater was Maltese-English bilingual speech-language pathologist experienced in transcribing and scoring of speech tests. The rater was provided with a set of guidelines on the scoring procedure. The correlation between the scores was analysed statistically in the same manner as the intra-rater reliability correlation.

Finally, intra-class correlations (ICCs) were carried out to analyse the degree to which the scores obtained from the three ratings of the live (1 rating) and recorded responses (2 ratings) correlate. The ICC spans between zero, (indicating that all the observed differences between scores are caused by measurement error) and one (when the scores are not at all influenced by random error) (Haas, 1995). A researcher therefore looks for an ICC as close as possible to one when establishing the reliability of a clinical assessment tool (Hayen, Dennis, Finch, 2007). Table 23 includes the correlations between corresponding items obtained from the raters.

Table 23

Intra-rater and inter-rater correlations

Assessments carried out at Time 1 and Time 2	Spearman correlations	p value	Intra class correlations			
			Single	p value	Average	p value

				measure		measure	
mNWRT(qu)	Intra-rater	.862**	.000	.813	.000	.929	.000
	Inter-rater	.881**	.000				
eNWRT(qu)	Intra-rater	.686**	.005	.702	.000	.876	.000
	Inter-rater	.831**	.000				
mNWRT(n)	Intra-rater	.886**	.000	.754	.000	.902	.000
	Inter-rater	.780**	.001				
eNWRT(n)	Intra-rater	.588*	.021	.666	.000	.857	.000
	Inter-rater	.851**	.000				

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

The results obtained from both the intra-rater and inter-rater reliability measure demonstrate strong correlations of statistical significance throughout all lists of nonword repetition. This could suggest two outcomes:

1. The child's responses are transcribed and scored in a similar way, whether they are heard live - directly from the child, or through an audio recording of the responses at a later date.
2. The manner in which the two raters transcribed and scored the responses was very similar for all lists.

4.2.2.2 Test-retest reliability. Each list was examined for test-retest reliability. 12 children (described in table 19 of section 4.2.1.3) were requested to repeat the nonwords in all four lists twice. A gap of two weeks was kept between test and re-test. Their responses were scored and the results obtained from time-1 and time-2 were correlated (refer to table 24).

Table 24

Test-retest correlations

Assessments carried out at Time 1 and Time 2	Spearman correlations	p value
mNWRT(qu)	.820**	.001
eNWRT(qu)	.449	.193
mNWRT(n)	.793**	.002
eNWRT(n)	.590	.073

**Correlation is significant at the 0.01 level (2-tailed)

The correlations for all four sub-tests were positive. However, a discrepancy between the Maltese and English based NWRTs was evident. Both Maltese tests (in quiet and in the presence of background noise) resulted in strong correlations of statistical significance. On the other hand both English tests showed a lower (moderate) correlation. Although both Maltese and English based tests were developed following the same criteria the results indicate that the Maltese-based test is more reliable in terms of test-retest.

4.2.2.3 Equivalence reliability. For the purpose of investigating the equivalence reliability of the NWRT lists, the sub-tests were divided in terms of *nonwords in quiet* and *nonwords in the presence of background noise*. Parallel forms reliability was investigated through the identification and administration of similar types of tests measuring the same variable. One challenge was to pinpoint suitable measures to use as a parallel form. Since the nonword lists were developed using the criteria put forward in the Cost Action ISO804, the researcher opted to correlate the Maltese and English nonwords in quiet with the Language-Specific Test for English (Chiat, Polišenská & Szewczyk, 2012). This list was also developed using the same criteria. The Language-Specific Test for English was read out and audio-recorded by the researcher in order to retain as much as possible the phonotactic characteristics of a Maltese speaker of English. This test was administered to a different

sample of children together with the English and Maltese-based nonword repetition tests developed in parallel for this research. The data from 95 Maltese children aged 5;00 to 5;11 years were collected and analysed by the researcher (Calleja & Grech, 2014) and for the purpose of this study the results (percentage error) obtained from each list were correlated. Table 25 shows these correlations and figure 17 provides a graphical representation of these results.

Table 25

Correlation between the English and Maltese-based NWRT and the Cost Action ISO804

Language-Specific Test for English

		Cost Action ISO804 - English	eNWRT(qu)	mNWRT(qu)
Cost Action ISO804 - English	Spearman Correlation	1	.688**	.644**
	Sig. (2-tailed)		.000	.000
	N	95	95	95
eNWRT(qu)	Spearman Correlation			.521**
	Sig. (2-tailed)			.000
	N			95

**Correlation is significant at the 0.01 level (2-tailed).

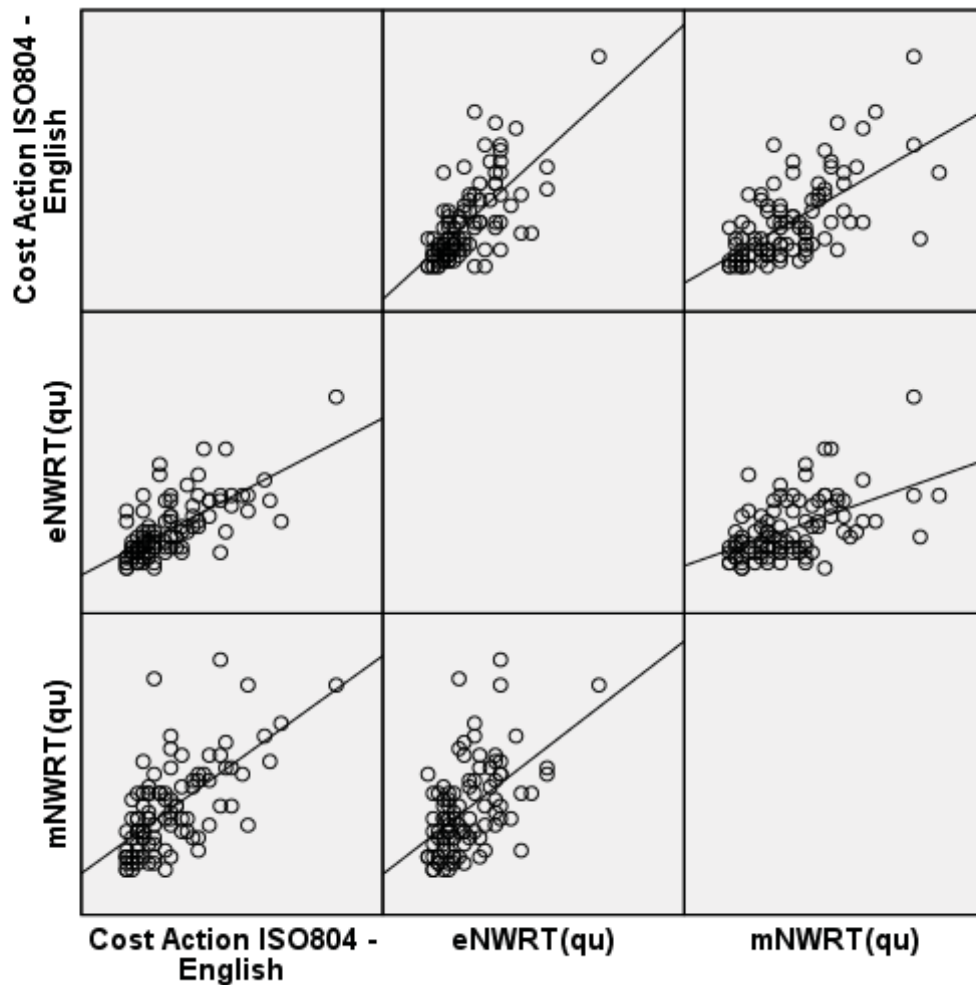


Figure 17 Scatterplot showing the correlations between each list

These results demonstrate a positive and statistically significant ($p = .000$) correlation between all three NWRTs. The eNWRT and the ISO804 list correlated best with a correlation coefficient of nearly .7. The mNWRT also resulted in a high-moderate correlation with the ISO804 list. Finally, the least correlation for this sample population emerged in the English and Maltese NWRTs, where a moderate correlation (above .5) was found.

The data obtained from the Maltese and English NWRTs were also correlated for the sample obtained throughout this research (children aged between 7;00 and 9;11 years). The results are shown in table 26.

Table 26

Correlation between the English and Maltese-based NWRT in quiet

		mNWRT(qu)	eNWRT(qu)
mNWRT(qu)	Spearman Correlation	1	.737**
	Sig. (2-tailed)		.000
	N	122	121

** . Correlation is significant at the 0.01 level (2-tailed).

In this sample population a strong and statistically significant correlation was obtained. The difference between the correlation results obtained from the sample of 5-year-olds and the older children could be due to the fact that the older cohort would have a greater and longer exposure to both languages.

Similarly to the NWRTs in quiet, the NWRTs in noise were also correlated (table 27).

Table 27

Correlation between the English and Maltese-based NWRT in noise

		mNWRT(n)	eNWRT(n)
mNWRT(n)	Spearman Correlation	1	.508**
	Sig. (2-tailed)		.000
	N	123	122

** . Correlation is significant at the 0.01 level (2-tailed).

A moderate statistically significant ($p=.000$) correlation was obtained between these two tests.

To date there are no established speech-in-noise tests validated on the Maltese population. Nonetheless, as part of a post graduate dissertation (Busuttil, 2015), two speech tests (Maltese Word Test of Hearing (MWTOH): one in quiet and one in noise) were developed using Maltese words and preliminary data were obtained. Busuttil (2015) administered her developed tests, together with the Maltese and English NWRTs in quiet and in noise on both typically developing adolescents and those with a cochlear implant. In addition, Busuttil (2015) ran an English speech recognition test – the Arthur Boothroyd (AB) Isophonemic Word Lists (Boothroyd, 1968). This test is widely used in the assessment of monolingual English speakers, and presents phonemically balanced consonant-vowel-consonant (CVC) words as stimuli. The AB lists used in Busuttil's (2015) study were recorded by a native British English female speaker. Permission was granted to the researcher (Appendix B - 1) to use these data in order to obtain correlations between the NWRTs, and the MWTOH, and AB lists; both in quiet and in the presence of background noise. All the tests in noise used multi-speaker babble as a noise source using a signal-to-

noise ratio of between +5 and +8 dB. These correlations are presented in tables 28 and 29, while the corresponding scatterplots are shown in figures 4.3 and 4.4.

Table 28

Correlation between the English and Maltese-based NWRT, the AB list, and the MWTOH in quiet

		AB list	MWTOH	eNWRT(qu)	mNWRT(qu)
AB list	Spearman Correlation	1	.890**	.867**	.867**
	Sig. (2-tailed)		.000	.000	.000
	N	22	22	22	22
MWTOH	Spearman Correlation	.890**	1	.883**	.890**
	Sig. (2-tailed)	.000		.000	.000
	N	22	22	22	22
eNWRT(qu)	Spearman Correlation	.867**	.883**	1	.960**
	Sig. (2-tailed)	.000	.000		.000
	N	22	22	22	22
mNWRT(qu)	Spearman Correlation	.866**	.890**	.960**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	22	22	22	22

** . Correlation is significant at the 0.01 level (2-tailed).

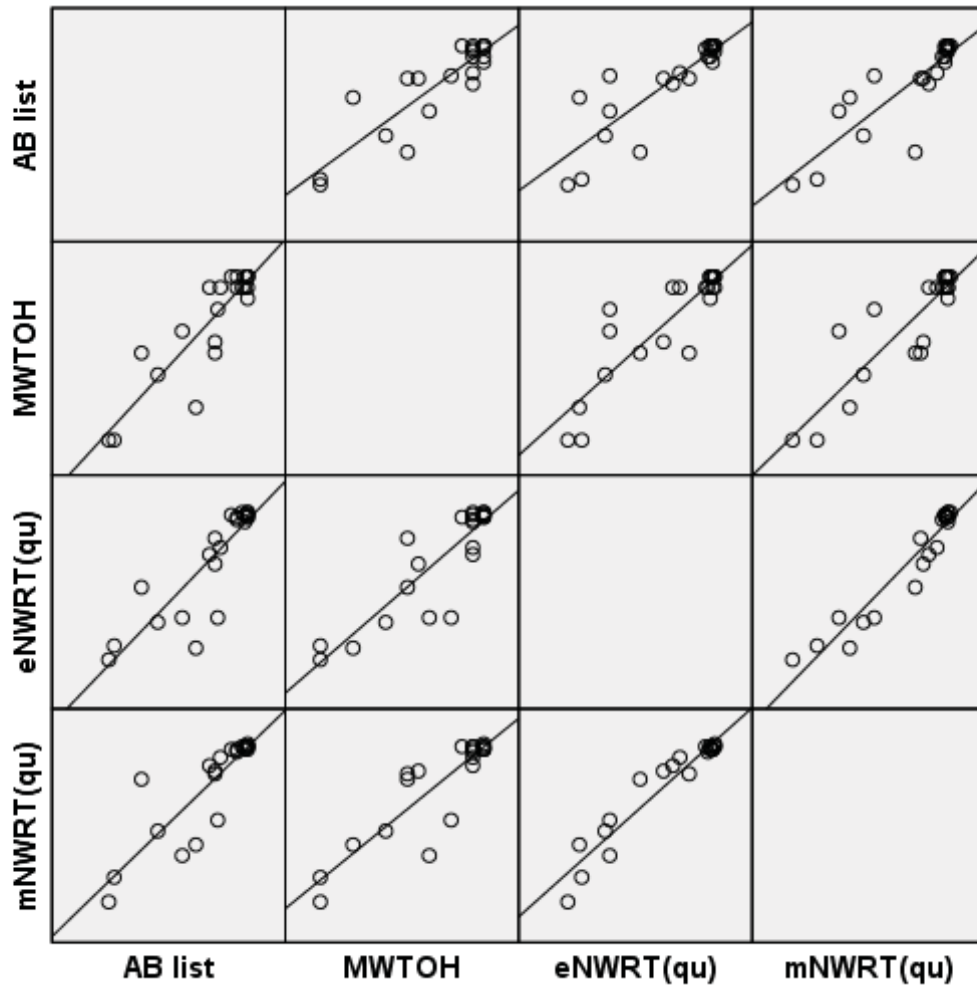


Figure 18 Scatterplot showing the correlations between each list

Table 29

Correlation between the English and Maltese-based NWRT, the AB list, and the MWTOH in the presence of multi-speaker babble

		AB list (noise)	MWTOH (noise)	eNWRT(n)	mNWRT(n)
AB list (noise)	Spearman Correlation	1	.937**	.935**	.838**
	Sig. (2-tailed)		.000	.000	.000
	N	22	22	22	22
MWTOH (noise)	Spearman Correlation	.937**	1	.951**	.935**
	Sig. (2-tailed)	.000		.000	.000
	N	22	22	22	22
eNWRT(n)	Spearman Correlation	.935**	.951**	1	.921**
	Sig. (2-tailed)	.000	.000		.000
	N	22	22	22	22
mNWRT(n)	Spearman Correlation	.838**	.935**	.921**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	22	22	22	22

** . Correlation is significant at the 0.01 level (2-tailed).

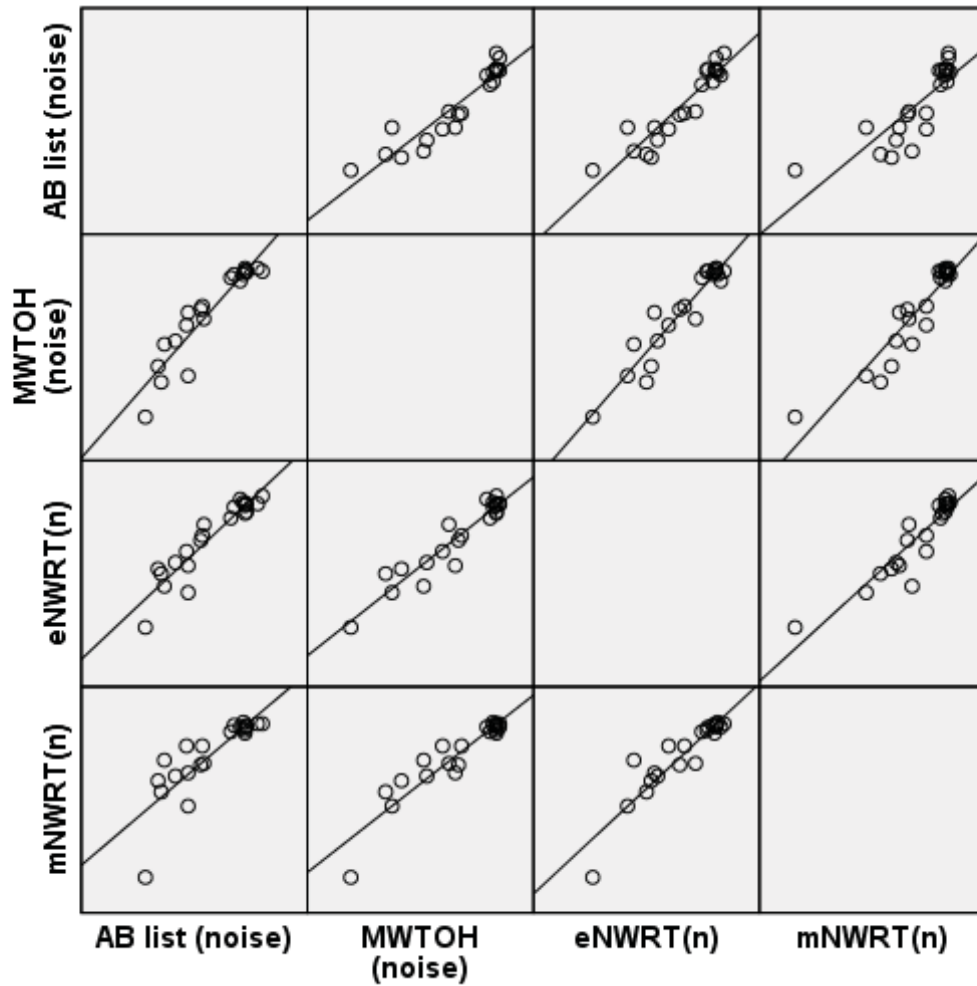


Figure 19 Scatterplot showing the correlations between each list

Of interest to this research was the correlation between the NWRTs, and the MWTOH and AB lists in quiet and in noise. The tables and scatterplots show very strong correlations (all above .8) with a statistical significance at the .01 level.

4.2.2.4 Validity testing – content. In addition to reliability testing, the lists underwent tests of validity. The reader is referred to section 3.6.2 for a detailed account of how the nonword lists were built. All nonwords were tested for content validity. This was determined by developing the tests in line with the Cost Action ISO804 methodology of nonword development (Chiat, 2015). Table 30 provides rationales in relation to the development on the nonwords.

Table 30

Content validity of methodology used for developing the nonwords

The nonwords developed were language specific.	Although NWR does not directly draw on vocabulary and syntax knowledge, children are more proficient at repeating nonwords that include phonological characteristics of real words in their native language. This could have implications on the performance of NWR in bilingual children (Chiat, 2015).
They varied in length (between 2 and 4 syllables).	Length effects have been found across languages, where the nonwords with longer syllables (such as 4 syllables) are produced with less accuracy than shorter nonwords (such as 2 syllables) (Stokes et al., 2006; Windsor et al., 2010).
Nonwords of different segmental complexity were constructed.	Children have been found to perform consistently better in nonwords made up of only single consonants when compared with nonwords containing consonant clusters (Archibald & Gathercole, 2006; Jones et al., 2010).
Nonwords were divided into high and low word-likeness.	Word likeliness has been found to correlate well with phonotactic probability (Polisenska, Chiat, & Szewczyk, as cited in Chiat, 2015). In turn, studies have shown that children repeat nonwords of higher phonotactic probability with more accuracy than those of lower phonotactic probability (Jones et al., 2010; Munson et al., 2005)

The total number of nonwords in the developed four lists amounted to 96. However, the initial amount of nonwords developed was 144: 72 Maltese-based and 72 English based. Content validity in terms of word-likeness was sought, where 20 bilingual Maltese speech-language therapy students were asked to rate the nonwords through a 5-point Likert scale. The nonwords that resembled real words were given a higher score. Following analysis of their feedback, the 48 nonwords rated highest in word likeness and 48 rated lowest were chosen to be entered in the final lists.

In order to obtain face validity of the lists, they were then passed on to an academic, who is also a speech-language pathologist and audiologist, within the Department of Communication Therapy for her judgement on the content of the list in terms of whether the tool would measure phonemic processing. The professional chosen was a Maltese-English bilingual speaker with an expertise in phonological development in Maltese children. She had recently developed and standardised an assessment of speech and language in Maltese children: the Maltese-English Speech Assessment (Grech, Dodd & Franklin, 2011). She was also involved in the development of Maltese and English-based nonwords as part of the COST Action ISO804. Upon confirmation of the appropriateness of the lists, all were audio-recorded.

With the aim of attaining content validity on the nonwords in noise lists, speech babble was added to one English-based and one Maltese-based list and given to a Clinical Senior Lecturer and Consultant in Audiovestibular Medicine with extensive clinical and research experience in the APD population. Following recommendations to alter the speech babble to one with little-to-no amplitude fluctuations, the two nonwords in noise lists were re-recorded and set at a signal to noise ratio (SNR) of approximately +5.

4.2.2.5 Concurrent and convergent validity. Through the data obtained in Busuttil's (2015) study, the strength of correlation and statistical significance between the Maltese and English NWRTs in quiet and in noise and the AB word lists was established in order to examine the concurrent and convergent validity of the tool. These correlations, as were shown in tables 4.13 and 4.14 above, demonstrate a statistically significant ($p=.000$) strong correlation (all above .8) between the NWRTs and the AB lists both in quiet and in noise. This indicates that speech perception and recognition skills measured through word and nonword lists generated very similar results.

4.2.2.6 Statistical Conclusion and Internal Validity. The relationship between each of the NWRTs and the independent variables was investigated. The entire sample was used: both typically developing and clinical samples. Of specific interest was to find out whether the tests yield statistically significant results for the clinical population (clinical validation). This was carried out to assess the capability of the NWRTs in quiet and in noise to differentiate between the performance of typically developing children and a clinical sample population. Despite the diversity in the clinical sample, this group was analysed as a whole due to the small sample size. Each child in the clinical sample was diagnosed through a clinical report, mainly psychological report, and in the case of ear pathology, ENT/audiological report.

Correlation results (as shown in table 31) demonstrate a statistically significant (at the .01 level), weak-to-moderate correlation between *pathology* and both NWRTs in quiet and the Maltese NWRT in noise. This indicates that there exists a relationship between the dependent variables (Maltese and English NWRT in quiet, and the Maltese NWRT in noise) and the independent (*pathology*) variable – in turn indicating some statistical conclusion validity and internal validity that the *pathology* variable caused the children in the clinical sample to perform worse in these tests. One test – the eNWRT(n) did not result in a

significant correlation with any of the independent variables, including *pathology*. This could indicate that this sub-test might not be strong enough to detect pathology. However, in order to verify this finding, a regression analysis (using generalised linear models (GLiMs) due to a non-normal distribution) was carried out. This method brings out the predictors (from the independent variables) of the dependent variables (the NWRTs). The results of the GLiM are shown in table 32. It emerged that the independent variable *pathology* was the only, or the strongest, predictor for *all* four lists.

Table 31

Statistical conclusion and internal validity (Scoring method: total % errors)

Scoring method: total % errors		Gender	Region	School Type	Age	Language	Pathology
mNWRT(qu)	Spearman Correlation	.010	-.169	-.027	-.008	-.009	.327**
	Sig. (2 - tailed)	.914	.063	.770	.928	.924	.000
	N	122	122	121	122	122	122
eNWRT(qu)	Spearman Correlation	.052	-.090	-.114	-.076	-.026	.431**
	Sig. (2 - tailed)	.568	.327	.212	.405	.780	.000
	N						
mNWRT(n)	Spearman Correlation	.070	-.091	.044	-.204*	.161	.321**
	Sig. (2 - tailed)	.441	.315	.632	.024	.075	.000
	N						
eNWRT(n)	Spearman Correlation	-.104	-.024	-.129	.030	-.076	.121
	Sig. (2 - tailed)	.252	.791	.159	.747	.405	.185
	N	122	122	121	122	122	122

Table 32

Predictors of each NWRT – regression analysis (GLiM)

		Wald Chi Square	p value
mNWRT(qu)	Phoneme error analysis	15.742 (<i>pathology</i>)	.000
eNWRT(qu)	Phoneme error analysis	4.299 (<i>pathology</i>)	.038
mNWRT(n)	Phoneme error analysis	20.957 (<i>pathology</i>)	.000
eNWRT(n)	Phoneme error analysis	4.113 (<i>pathology</i>)	.043

4.3. Reliability and validity of the modified tests in the assessment battery

4.3.1 Gaps in noise. The relationship between the GIN test and the independent variables was investigated. The predictors of the percentage correct subtests (right and left) were consistently *Age group* and *Primary Language*, while the predictors of the GDT were *Gender* (right ear) and *Age group* (left ear). The significance of these predictors are shown in table 33.

Table 33

Predictors of each GIN subtest – regression analysis (GLiM)

		Wald Chi Square	p value
GDT (right)	Gender	5.802	0.016
GDT (left)	Age	9.552	0.008
% correct (right)	Age	6.193	0.045
	Primary language	4.848	0.028
% correct (left)	Age	8.401	0.015
	Primary language	7.088	0.008

4.3.2 Duration patterns test (DPT). In 1994, Musiek obtained normative values for young adults on the Duration Patterns test, suggesting a cut-off score of 73%. Bellis (2003) obtained further data across larger age groups ranging between 7;00 years to adults. Of relevance to this study, the normal cut-off scores obtained by Bellis (2003) were as follows:

7;00 – 7;11 years: 25%

8;00 – 8;11 years: 35%

9;00 – 9;11 years: 54%

Friberg and McNamara (2010) have evaluated the reliability and validity of the DPT amongst other assessments of auditory processing using criteria for test validity modified from McCauley and Swisher (1984). The DPT was found to be criterion-referenced, due to the fact that there was no evidence of standardization of the tool mentioned in its manual. Both the sensitivity (true positive rate) and specificity (true negative rate) were documented as being .86 and .92 respectively (Musiek, 1994; Musiek, Baran, & Pinheiro, 1990). Musiek et al. (1990) compared the performance of the DPT in three groups: normal listeners, listeners with cochlear pathology, and individuals with CANS lesions. Their results indicated no significant difference in performance between the normal listeners (mean 88.3% in the right and 88.7% in the left) and those with a cochlear loss (mean 86.1% in the right and 88.9% in the left). On the other hand the individuals with CANS lesions performed significantly worse (mean 44.9% in the right and 43.3% in the left).

The DPT adapted version in this study was assessed for reliability using the test-retest method. 12 TD children were required to complete the task twice with a gap of between 1 and 2 weeks between each test. The results obtained were correlated and tabulated as follows (table 34).

Table 34

Test-retest reliability of the Duration Patterns test

Duration Patterns test (right)	Spearman Correlation (Time 1 – Time 2) Sig. (2-tailed)	.545 .067
Duration Patterns test (left)	Spearman Correlation (Time 1 – Time 2) Sig. (2-tailed)	.630* .028
Duration patterns test (combined score)	Spearman Correlation (Time 1 – Time 2) Sig. (2-tailed)	.677* .016

*. Correlation is significant at the 0.05 level (2-tailed).

Test-retest correlations were computed for right and left ears separately, as well as for the combined score. Moderate correlations were obtained throughout, with those of the left ear and the combined score being statistically significant.

This test method underwent validity measures in terms of statistical conclusion and internal validity. A regression analysis between the dependent and independent variable showed *Pathology* to emerge as the strongest predictor, followed by *Age group* and *School type* (table 35). The strength of the *Pathology* predictor could indicate internal validity that the pathology present caused the result of the DP test to be significantly different, with the TD obtaining an average of 18.8% and 16.9% better scores in the right and left ears respectively. This could further indicate clinical validity of this tool for clinical groups.

Table 35

Predictors of each DPT – regression analysis (GLiM)

		Wald Chi Square	p value
Right	Pathology	16.860	.000
	Age	5.694	.058

Left	Pathology	14.053	.000
	Age	7.662	.022
	School type	6.830	.033

4.4 Discussion

The results presented in this chapter are discussed next in relation to research question 1 (Chapter 2 *Literature review*, section 2.13).

Research question 1: How reliable and valid are the developed and modified tools?

Perhaps the greatest challenge in determining the reliability and validity of this tool stems from the lack of gold standard and great variability across centres in the assessment of auditory processing disorders. If one were to follow Ferguson's (2014) suggestions in establishing a strong test, then the tool is to have good construct validity and test-retest reliability, as well as a high sensitivity and specificity in a specific population. However, achieving high sensitivity and specificity in a tool could be problematic when one is to consider the reported high comorbidity of children reported to present with a profile of auditory processing disorder as well as having a diagnosis of some other neurodevelopmental disorder. For this reason it might make more sense take an approach of examining the reliability and validity of tools assessing the different skills that have been reported to underlie auditory processing disorders, such as understanding speech in noise, temporal processing and dichotic listening. The reader is reminded that in examining the reliability and validity of the tool its respective consistency and credibility is being sought.

4.4.1 Reliability and validity of the developed tools

4.4.1.1 QCAP. With only twenty 5-point Likert scale items forming the test, the QCAP could be a quick and attractive tool to quantify the perceived listening difficulties across different situations. Table 4.20 summarises the reliability measures carried out on the QCAP. The inter-item and split-half reliability outcomes indicate very good homogeneity

(internal consistency) of the tool, suggesting that all the items on a scale seem to measure one construct (Heale & Twycrosse, 2015); that of listening difficulties across an array of situations, and the possible consequences of these difficulties.

The stability of the QCAP was tested through test-retest and equivalence reliability. Through test-retest, there was a positive and high correlation between the results obtained on the two occasions, indicating that the questionnaire outcomes should not change over a specific amount of time between administrations. Test-retest reliability of the QCAP has already been previously investigated. Cassar (2014) reported a very good test-retest reliability with a Cronbach's Alpha score of 0.997. This result was consistent with the findings of the adapted version of this study, further confirming its stability in this respect.

Table 36

Summary of reliability measure results from the QCAP

Reliability	Inter-item	Split-half	Test-retest	Equivalence
measures				
QCAP	.922**	.884**	.940**	-.401*

*. Correlation is significant at the 0.05 level (2-tailed).

** . Correlation is significant at the 0.01 level (2-tailed).

Equivalence reliability for the QCAP was attempted as a means of analysing the reliability of the new questionnaire with an already established questionnaire found to conceptualise behavioural findings related to APD. In light of the previous findings related to screening questionnaires (refer to section 4.2.1.4), the researcher has opted to devise this tool as an aid to highlight auditory behavioural concerns in Maltese children rather than as a

screening tool of APD. The moderate and significant correlation between the two questionnaires suggests that the QCAP might measure the same behavioural characteristics reported in the CHAPPS. However, this result needs to be interpreted with caution due to the differences evident between the two tools.

The validity of the QCAP was assessed in terms of content validity, convergent and concurrent validity, and statistical conclusion and internal validity (sections 4.2.1.5 to 4.2.1.7). A validated questionnaire would be useful in picking up the listening difficulties widely reported in children diagnosed with, or suspected of having APD (Moore et al., 2013). Attempting to extract validity measures for this questionnaire was of importance to this study, especially in light of reports that many questionnaires used to screen APD in general have not been validated (AAA, 2010; Moore, 2012; Moore et al., 2013). On the other hand, the validation of a questionnaire investigating behaviours commonly linked with auditory processing is also complicated due to the lack of consensus about the construct to be investigated (de Wit et al., 2016). The QCAP results compared with the CHAPPS gave rise to a significant moderate correlation in this sample. Although there seems to be little known validity data on the CHAPPS, studies have shown poorer scores from children with APD in this questionnaire (Ferguson et al., 2011; Iliadou & Bamiou, 2012). This demonstrates the possibility of the QCAP extracting similar findings to the CHAPPS. One area that warrants further investigation for the QCAP is the influence or relation with cognitive factors. For example, Barry, Tomlin, Moore, and Dillon (2015) examined four questionnaires used in the assessment of auditory processing, and their ability at detecting the presence of listening difficulties. While the authors reported all questionnaires to be sensitive to listening difficulties, they also correlated with measures of cognition used in the study. The effect of cognition has also been examined in relation to the CHAPPS (Moore et al., 2010), with similar outcomes to the Barry et al. (2015) study. Moore et al. (2010) found that in 1469

mainstream school children aged between 6 and 11 years, the variance in the CHAPPS was primarily accounted for by factors of cognition and attention. These findings thus elicit queries as to which construct the questionnaires are tapping into: listening, cognition, or perhaps an amalgamation of the two.

4.4.1.2 Nonword repetition tests (NWRs). Table 37 summarises all the reliability measures carried out for the four nonword repetition tasks. The inter- and intra-rater reliability measures in speech perception tests were achieved by comparing the phonetic transcriptions of all listeners (Johnson & Danhauer, 2002). Within this study significant and strong or moderate correlations emerged in all four subtests in terms of both intra- and inter-rater reliability. The inter- and intra-rater reliability of these four lists has been previously investigated locally using a different age group. In a study investigating speech tests in the assessment of hearing impairment, Gabriele (2017) carried out reliability and validity measures of an array of speech tests in groups of young adults with normal hearing and a hearing impairment. Similar to the current study, Gabriele (2017) reports strong and significant correlation coefficients for both inter- and intra-rater scores. She also found no statistical significance between scores, further indicating good inter- and intra-rater reliability.

Table 37

Summary of reliability measure results from the NWRs

	Sub-tests			
	mNWRt(qu)	eNWRt(qu)	mNWRt(n)	eNWRt(n)
Inter-rater	.881**	.831**	.780**	.851**
Intra-rater	.862**	.686**	.886**	.588**
Test-retest	.820**	.449	.793**	.590
Equivalence with Cost Action ISO804 – English	.644**	.688**		

Reliability measures	list				
	Equivalence with MTOH in quiet and in noise	.883**	.890**	.951**	.935**
	Equivalence with AB list in quiet and in noise	.867**	.866**	.838**	.935**
	Equivalence when comparing the Maltese and English subtests	.737** (current study) .960** (data used from Busuttil (2015) study) .521** (data used from Calleja & Grech (2014) study)		.508** (current study) .921** (data used from Busuttil (2015) study)	

The test-retest reliability measures in this study demonstrate a strong significant correlation coefficients for both Maltese subtests and moderate correlations for the English subtests. This result indicates that the Maltese subtests might be a more reliable test for this population in terms of consistency over time. Gabriele (2017) also reports test-retest reliability results for the Maltese and English NWRs in quiet and in noise. Her study brought out strong statistically significant correlations in all four subtests, suggesting good test-retest reliability for her population under test. The discrepancy in correlation strength of the English NWRs between the two studies could be due to the age difference between the subjects. Sasisekaran, Smith, Sadagopan, and Weber-Fox (2010) have shown that adults tend to repeat nonwords with more accuracy and coordinative consistency than children. Furthermore, while keeping in mind that the primary language of most subjects was Maltese, there might have been increased variability in the production of the English (second language) nonwords.

4.4.2 Reliability and validity of the modified tests

4.4.2.1 Gaps in noise. The reader is referred to the literature review chapter (section 2.7.2.3) for an overview on reliability and validity studies of the GIN. Locally, this

has been investigated mainly through local dissertations, supervised by the researcher. Cassar (2014) examined the performance on the GIN in typically developing children. 41 children (17 boys and 24 girls) aged between 7;00 and 9;11 years completed the GIN test using the same methodology and subject age group as this present study (refer to Methodology chapter, section 3.2.3.4). As in this study, Cassar's subjects were asked to count the noise intervals rather than the gaps. Subsequently, the respective number of gaps detected was calculated. The outcomes of this study were similar to the reported international studies. There were no statistical differences across age groups, gender or between ears. Her study also included test-retest reliability, obtaining a Cronbach's Alpha value of 0.740. This implies good test-retest reliability for her study. Test-retest and inter-list reliability in 16 Maltese children have been further investigated by Hales (2016). His study also used the same GIN administration methodology and subject age-group as this research. Hales reports no statistically significant difference between 'time 1' and 'time 2', and mainly moderate correlations in both ears when the GIN was scored in terms of GDT and percentage correct. Similarly he reports no statistically significant difference between the four lists included in the assessment. The study suggests good test-retest and inter-list reliability for the GIN in this subject population.

The current study built on the results obtained by Cassar (2014) and Hales (2016) by carrying out a preliminary investigation of the clinical validity in children with neurodevelopmental disorders. The GiLM result within this research revealing that the independent variable '*pathology*' was not a predictor of the GIN, could have implications for clinical validity of the tool in this test population. This result is however to be interpreted with great caution due to the variety of neurodevelopmental disorders included in this study's small clinical sample. This outcome is consistent with local research investigating the auditory processing skills in clinical populations, in which no statistically significant difference in the GIN performance was found in TD children and those diagnosed with

ADHD, LI, and LitD (Tabone et al., 2016). The performance of these groups will be further discussed in relation to the literature in the next chapter (Quantitative analysis and discussion, section 5.7.2).

4.4.2.2 Duration Patterns Test (DPT). Reliability outcomes of the DPT have been described in various studies (e.g. Frascá, Lobo & Schochat, 2011; Lilly, 2014; Neijenhuis, Stollman, Snik & Van der Broek, 2001) with good test-retest reliability being reported in both adults and paediatric populations. However, the adapted DPT method used in this research (as described in the Methodology chapter, section 3.2.3.4) warrants reliability outcomes for this population. The moderate statistically significant correlations between test and retest suggest good stability of the tool over time. Test-retest reliability DPT using the same method and age group as this research has also been reported in Hales' (2016) study where, consistent with the current study, moderate correlations emerged. In addition, Hales (2016) found no statistically significant difference between 'time 1' and 'time 2' in his study, leading him to the conclusion of moderate to good test-retest reliability. Therefore, although additional research is warranted to further strengthen the outcomes, the results obtained to date suggest good test-retest reliability for this tool.

The results from the regression analysis show that the independent variable '*pathology*' was the strongest predictor of the DPT. This outcome indicates that the DPT might be a valid tool to extract difficulties with auditory temporal ordering and sequencing in Maltese children with a neurodevelopmental disorder. But with keeping in mind the small and varied clinical sample, further research is needed to investigate this preliminary finding. The outcome might also suggest that, although the children in the clinical group were all reported by their parents/carers to exhibit listening difficulties, these might not be manifested through an impairment in auditory temporal sequencing/ordering.

4.4.3 Reliability and validity of the previously-established tools

4.4.3.1 Dichotic digits. Studies reporting normative values of the DDT (Musiek, 1983) and its clinical validity in detecting disorders of the CANS (Musiek, 1983; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991) have been reported in section 2.7.1 (Chapter 2, literature review). As will be shown in the next chapter (chapter 5: *Results - Quantitative analysis*, figures 5.28 and 5.29) the average scores for a sample of Maltese children are presented and compared with the scores obtained by the clinical group in the study. The clinical group were found to perform significantly worse than the TD group. The same pattern also emerged in Tabone et al. (2016), who found that the children diagnosed with ADHD, DLD, and literacy difficulties performed significantly worse than the controls. Poor performance has also been reported in individuals with CANS dysfunction (Musiek et al., 1991). This suggests that the Dichotic Digits task could be a clinically valid tool in assessing top-down control and attention processes in these populations. The DDT performance of the TD and clinical groups in this study are further discussed in relation to the current literature findings in the following chapter (Quantitative analysis and discussion, section 5.7.2)

4.4.3.2 Frequency Patterns Test. The FPT was examined for sensitivity and specificity in a study carried out by Musiek and Pinheiro (1987). The study looked at the performance of three groups on the FPT. The authors adopted the criterion of a 75% cut-off point between normal and abnormal performance for adults. This cut-off point was consistent with a later study on normally hearing adults (Musiek, 1994), where a cut-off point of 78% was recommended. The FPT was found to be sensitive to cerebral lesions (83% sensitivity) and resistant to cochlear losses. It was further shown to have a high specificity of 88.2% when comparing cerebral versus cochlear lesions (Musiek & Pinheiro, 1987). On the other hand it was reported that this test was not sensitive to brainstem lesions.

Hales (2016) reported test-retest reliability outcomes on the FTP in Maltese children of the same age group as this research. He found no statistically significant difference between the group performance at time 1 and time 2 indicating good stability over time. As regards validity, this study compared the performance the TD and clinical groups in order to examine statistical conclusion validity, i.e. whether there is a relationship between the FPT and the independent variable '*pathology*'. The results (as shown in chapter 5, sections 5.4.4.6 and 5.6.4.3) indicate that there is no relationship between the two variables. Despite claims of poor frequency patterning skills in children with DLD (Bishop et al., 1999) and literacy difficulties (Sharma et al., 2006), this research could not confirm the FPT to be clinically valid in detecting processing impairments of frequency in Maltese children with neurodevelopmental disorders.

4.4.3.3 Sentence Imitation Test (SIT). The SIT (Grech, Franklin, & Dodd, 2011) was analysed for validity and reliability as part of a larger language assessment on Maltese children – the Language Assessment for Maltese Children (LAMC). The SIT was correlated with the verbal comprehension and narrative scores in children up to the age of 6 years. The authors also carried out multiple regression analysis, with the results showing that the SIT is a predictor of receptive language (Grech et al., 2011). The tool also underwent test-retest and inter-rater reliability measures, in which it was reported high reliability in both.

4.5 Summary

This chapter described the measures used to investigate reliability and validity of the assessment protocol, followed by a discussion of the outcomes in relation to the literature.

The points below summarise the main findings:

- The questionnaire demonstrated strong significant reliability in terms of test-retest, inter-item, and split-half measures. It was also found to show moderate significant equivalence reliability with the CHAPPS. This significant correlation with the CHAPPS suggested concurrent validity. All statements presented in the QCAP were supported by references in the literature to strive for content validity as much as possible. The significantly worse scores obtained by parental report of the children in the clinical group suggest the tool to be clinically valid in detecting difficulties related to auditory and listening skills.
- The NWRTs in quiet and in noise were found to have good inter- and intra-rater reliability. This outcome is consistent with other local research (Gabriele, 2017). The Maltese NWRTs showed stronger significant correlations compared with the English subtests suggesting the former to be a more reliable test for consistency over time.
- The modified temporal processing tests were found to show strong test-retest reliability for the GIN and DPT. This study could not confirm the GIN to be clinically valid in detecting differences in temporal resolution in children with neurodevelopmental disorders, suggesting that not all these children exhibit difficulties in temporal resolution. In contrast, the DPT results indicate that the test might be valid to extract difficulties with auditory temporal ordering and sequencing in Maltese children with a neurodevelopmental disorder.

In the next chapter, the reader is presented with the quantitative results that emerged in terms of descriptive statistics for the individual tests, and the inferential statistics across subtests and independent variables.

Chapter 5. Results – Quantitative Analysis

5.0 Chapter overview

Throughout this chapter the scores of the participants on the assessment battery of auditory processing will be explained. The first section provides the descriptive statistics of each test. The inferential statistics exploring the significance of the difference between variables, regression analyses and correlations across groups and tests are then reported.

One objective of this study is to develop trends regarding the performance of Maltese-English bilingual children on a battery of auditory and language processing tasks, and hence the data collected from a sample of typically developing (TD) children were analysed. The

data obtained from the children with a reported diagnosis of neurodevelopmental difficulties were later used for comparative reasons. They were furthermore included in the regression analysis together with those of the TD children to verify the diagnostic strength of each assessment in the battery.

5.1 Normality testing

Normality testing of data is considered to be an essential step prior to selecting and carrying out statistical analysis, since many statistical procedures (specifically the parametric tests) assume normal data distribution and the validity of their outcome is dependent on it (Laerd Statistics, 2013; Ghasemi & Zahediasl, 2012). This type of testing is carried out through two main methods: graphically and numerically. Both methods were adopted in this research. The graphical method allows readers to visualise and judge the data distribution. One common form is through a histogram, which portrays a plot of the measured value against the frequency. The histogram allows the reader to make a visual judgement about the distribution shape (how 'bell-shaped' or symmetrical is it?) (Peat & Barton, 2005). Another graphical form of showing normality is through a Q-Q plot. This method sorts and ranks the data to create z-scores, so that the actual z-scores are plotted against the expected z-scores. Data which are normally distributed would produce a straight diagonal line (Ghasemi & Zahediasl, 2012). When data are not normal, the Q-Q plot augments the deviations from proposed distribution at the tail ends.

Finally, the data can be portrayed in the form of a box plot. This displays the median score by means of a horizontal line inside a box displaying the 25th to 75th percentiles (interquartile range). This graphical view also provides whisker lines of the maximum and minimum values within one and a half times the interquartile range in both directions, as well

as the outliers (Peat & Barton, 2005). From the box plot, data of normal distribution can be recognised through a pattern of the horizontal line passing through the centre of the box and slightly longer symmetric whisker lines (Elliot & Woodward, 2007).

Numerical methods of assessing for normality accompany the graphical methods. Two common numerical methods include the Kolmogorov-Smirnov (K-S) (Kolmogorov, 1933) and Shapiro-Wilk (S-W) (Shapiro & Wilk, 1965) tests. Both these tests are based on the assumption that the population distribution is normal (the null hypothesis). In turn, their alternative hypothesis is that the population is not normally distributed (Albright, Winston, & Zappe, 2010), so that if the result of the computation is significant (<0.05) the distribution is non-normal (Ghasemi & Zahediasl, 2012). Both these tests can be computed through the SPSS software.

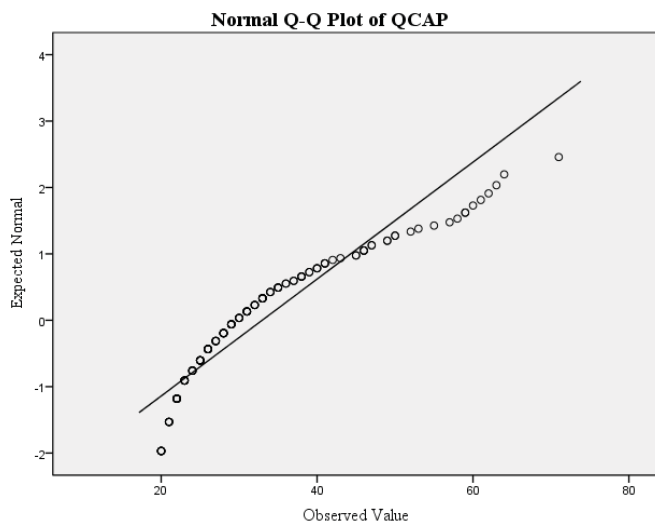
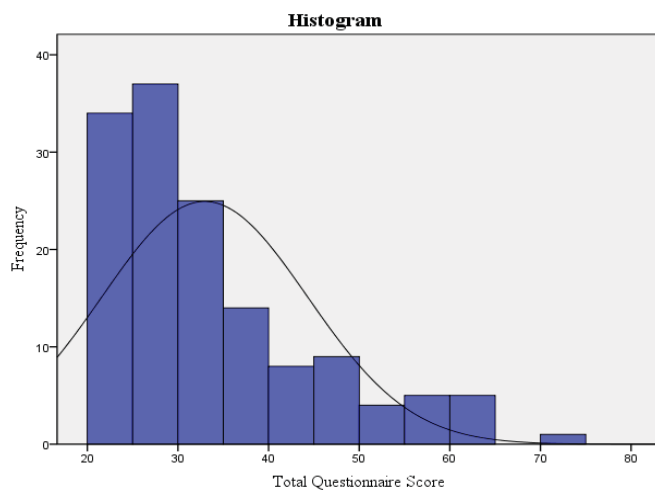
The K-S test is often used when the sample size is large (Sen & Srivastava, 1990). It evaluates whether the variation between the observed and the theoretical normal distribution is due to chance, in which case the data are considered normal (de Vaus, 2002). The limitation of this test is that it is very sensitive to extreme values (Ghasemi & Zahediasl, 2012), so that when large samples are used even a slight deviation from normality could result in low levels of significance (de Vaus, 2002). The S-W test is often the test of choice when small sample sizes (<50) are involved (Sen & Srivastava, 1990). It is less conservative than the K-S test (Riffenburgh, 2012) and has been suggested as a more reliable test and a better choice of normality testing than the K-S, especially when sample sizes are not large (Thode, 2002; Rovai, Baker, & Ponton, 2013).

In addition to the K-S and the S-W tests another method of assessing normality is through the skewness and kurtosis of the data distribution. This method is reliable in the testing of both small and large samples (Kim, 2013). Skewness assesses the symmetry of the

data and kurtosis examines the ‘peakedness’ of the distribution. The closer the values are to zero the more normal is the distribution (Schinka & Velicer, 2003). When using skewness and kurtosis, normality is tested through the conversion into a z-score. It has been proposed that as a general rule, skewness and kurtosis z-score values between ± 2 are considered to be of a normal distribution (Field, 2013; George & Mallery, 2010). However, it is also mentioned in the literature that the value of the accepted skewness and kurtosis z-scores for normality should vary depending on the sample size (Field, 2013; Kim, 2013). Specifically, Kim (2013) explains that samples of $n < 50$ data of normal distribution should have skewness and kurtosis z-scores of in between ± 1.96 , while in larger samples ($50 < n < 300$) the z-score value increases to a range of ± 3.29 . In order to obtain this score the skewness and kurtosis values are divided by their standard error. If their result is greater than the recommended z score (± 1.96 or ± 3.29), it suggests that the data are not normal with respect to that statistic (Rose, Spinks, & Canhoto, 2015). Since this study includes a sample size of 101 typically developing children, the z-score value of ± 3.29 will be considered in assessing for skewness and kurtosis. In combination with the skewness and kurtosis values, attention can be given to the mean (average) and median (the centre value) scores. When the data distribution is symmetric (indicating a skewness score within the normal range), the mean and median scores should be very similar (NIST/SEMATECH, 2012). With normal scores of skewness one would then look into the kurtosis score (Wuensch, 2016).

5.1.1 Normality testing of the assessment battery for auditory processing. All subtest results were initially tested for normality using the entire sample. Next, the normality testing of the QCAP is explained. The reader is referred to appendix C (Figures and tables related to chapter 5), sections C - 1 to C - 3 for an overview of the normality testing on the rest of the subtests forming the assessment battery.

Questionnaire of Central Auditory Processing (QCAP).



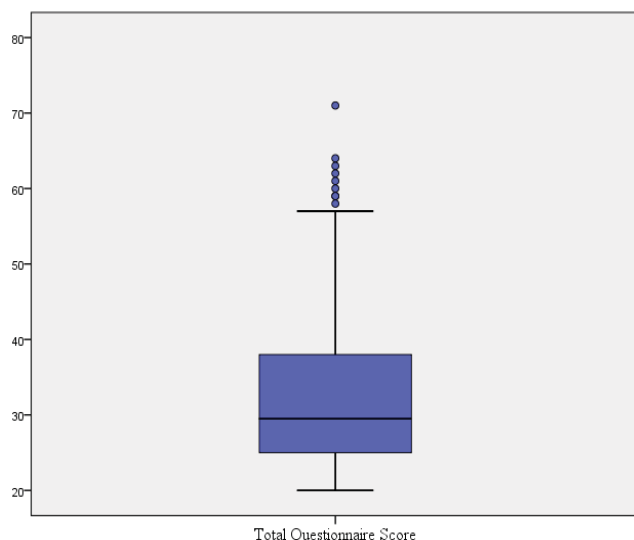


Figure 20 Graphical normality test results of the QCAP

The graphical outcomes of the normality testing (figure 20) indicate data of a non-normal distribution throughout. The histogram displays a right skew, demonstrating that parents scored low in terms of their children's auditory difficulties. This meant that the parents did not perceive their children as having much difficulty in terms of auditory / listening skills. The Q-Q clearly reveals that the observed value points deviate from the 'expected normal' line, while from the box plot one would note asymmetrical whisker lines with the majority of children's scores ranging between approximately 25 and 38.

The numerical methods of normality testing agree with the graphical methods. On initial observation one would note that the mean and median values differ (table 38) suggesting skewed data. Furthermore, the skewness z-score was greater than the proposed z-scores of ± 3.29 . Finally, the K-S and S-W tests of normality both indicated data of consistent non-normal distribution with the significance level of both tests being less than the 0.05 cut-off point associated with normal distribution (table 39).

Table 38

Descriptive statistics including skewness and kurtosis values: QCAP

		Statistic	Std. Error	z score	
Total QCAP Score	Mean	32.95	.953		
	95% Confidence Interval for Mean	Lower Bound	31.07		
		Upper Bound	34.84		
	5% Trimmed Mean	32.00			
	Median	29.50			
	Variance	129.026			
	Std. Deviation	11.359			
	Minimum	20			
	Maximum	71			
	Range	51			
	Interquartile Range	13			
	Skewness	1.238	.203	6.10	
	Kurtosis	.952	.404	2.35	

Table 39

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Total QCAP Score (% subjective difficulty)	.153	142	.000	.874	142	.000
Total QCAP Score (% subjective difficulty) – after transformation of data	.097	142	.002	.945	142	.000

a. Lilliefors Significance Correction

Generally, it has been proposed that if the data are normal (i.e. distributed in a Gaussian manner), parametric tests should be used. Conversely if the data are non-normal, non-parametric tests should be selected. Therefore from the normality testing that was carried out for all the subtests of this test battery one would conclude that since the majority of the data are of a non-normal distribution non-parametric tests would be the method of choice for the statistical analysis. While some advantages of non-parametric testing have been described, such as being relatively freer from assumptions concerning population distribution, they do have a lower statistical power than their comparable parametric tests (Weinberg & Abramowitz, 2008; Suresh, 2014). In addition, this ‘automatic’ approach of choosing the type of test is not recommended (Motulsky, 2010). Literature has shown that the *sample size* should also determine the type of test used. Specifically, the *central limit theorem* states that in using a random sample; the larger the sample, the more closely it

approximates a normal distribution (de Vaus, 2002). This implies that parametric tests could be used even with data of a non-Gaussian distribution (Field, 2009; Elliott & Woodward, 2007). While some authors suggest that samples of larger than 30 or 40 (Pallant, 2007) fall under this theorem, others have proposed larger sample sizes, such as 100 or more (de Vaus, 2002). This research uses a random sample of 101 typically developing children, so that according to the central limit theorem parametric tests *could* be selected to perform the statistical analyses even though many tests resulted in data of non-normal distribution. The use of parametric tests might be more plausible since nonparametric tests are more efficient in evaluating categorical and rank-order data (Sheskin, 2003). The data presented in this research are of interval and ratio scales which warrant more than an analysis of ranks. However, it *still* cannot be excluded that the data distribution was generally non-normal. An attempt at normalising the data was done as shown in appendix C, sections C - 1 to C - 3. This resulted in an increased number of subtests exhibiting skewness and kurtosis z score values within the ± 3.29 range and therefore indicating data of normal distribution. In contrast, both the S-W and K-S tests of normality *still* displayed p values of less than the 0.05 cut-off point associated with normal distribution in nearly all subtests: suggesting non-normal data. In light of these contrasts, the data were further analysed for normality categorised by their independent variable (presented in section 5.4). The subsequent inferential statistical analysis of these data will be implemented through both parametric and nonparametric means. Where the data are non-normal, the nonparametric tests will be presented in the main text with the parametric equivalent referred to accordingly. Where the data are normal, the parametric tests will be used for statistical analysis.

5.2 Factor Analysis of the Tool

Factor analysis is a statistical technique which uses correlations between variables in order to reveal any relationship patterns (Kline, 2014)²¹. In relation to this research it is of interest to extract relations between subtests with the aim of grouping them under one category or *factor*. This is especially important when considering the fact that to date there is still no “gold standard” in diagnosing APD. Based on a consensus agreement ASHA (2005) highlighted five main auditory measures necessary in the diagnosis of APD: auditory discrimination, temporal processing, dichotic listening, monaural low-redundancy speech, and binaural interaction. The BSA (2011) emphasised the use of assessing two main components: speech and non-speech stimuli due to the possibility of co-morbid language processing difficulties (Ahmmed, Ahmmed, Bath, Ferguson, Plack, & Moore, 2014). A different perspective of attention and working memory underlying APD has also been proposed by Moore et al. (2010). Carrying out a factor analysis of the components of this research could categorise the subtests under factors based on relationship patterns between them.

Prior to carrying out the factor analysis, the data were checked for suitability to perform this test. This was done through the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and the Bartlett's Test of Sphericity. The KMO measure is based on the principle that if the variables share common factors, then a correlation between them should be evident (Munro, 2005). The KMO measure provides a score of between 0 and 1. The closer the value is to 1 the better are the patterns of correlations and the more likely the factor analysis would generate distinct reliable factors (Field, 2005). Values greater than 0.5 are

²¹ It is necessary to have a sample of at least 100 in order to perform this procedure (Dawis, 2000). This research study satisfies this requirement.

acceptable (Cerny & Kaiser, 1977), with values above 0.7 being considered as good correlations (Hutcheson & Sofroniou, 1999). The Bartlett's Test of Sphericity provides a score of probability, with a low probability – less than .05 (Rasli, 2006) supporting the use of factor analysis (Munro, 2005).

5.2.1 The assessment battery. Factor analysis of the assessment battery was carried out to highlight patterns between subtests and form categories based on relationships between them. The KMO and Bartlett's Test of Sphericity are tabulated below (table 40). The results revealed a KMO score above 0.7 and low probability value, which support the use of factor analysis.

Table 40

KMO and Bartlett's test of the assessment battery

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.761
Bartlett's Test of Sphericity	Approx. Chi-Square	840.805
	df	136
	P-value	.000

The data were extracted in terms of Eigenvalues and a scree plot, which determine to amount of factors to retain in the test battery. Criteria have been suggested as to where the cut-off point should be in order to determine the amount of factors to be retained. For example, Kaiser (1960) recommended that factors greater than the eigenvalue of 1 should be retained; Jolliffe (1986) suggested a cut-off value of .70. The limitation of these cut-off points is that they could overestimate the number of extracted values (Field, 2009). In this case a scree test, which combines the eigenvalues and factors, could be used. The

recommendation following the scree test is that only the number of factors above the point of inflection should be kept (Yong & Pearce, 2013). Table 41 demonstrates the variance explained by factors. A greater eigenvalue related to a factor denotes that more variance is explained by that factor (Kline, 2014). The table shows that there seem to be four components above the eigenvalue of 1 evident in this assessment battery: two strong components accounting for 50.54% cumulative percentage of variance and two weaker components. Nevertheless, the scree plot displays a point of inflection at the third component, which would suggest two components as can be seen in figure 21. For this reason factor analysis will be carried out using both 4 and 2 components in an attempt to extract the most plausible explanation of relationship patterns and come up with a direct interpretation for each component.

Table 41

APD assessment battery: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.834	34.319	34.319	5.834	34.319	34.319	3.503	20.603	20.603
2	2.758	16.226	50.545	2.758	16.226	50.545	3.202	18.835	39.439
3	1.528	8.988	59.533	1.528	8.988	59.533	2.582	15.189	54.628
4	1.317	7.745	67.278	1.317	7.745	67.278	2.151	12.650	67.278
5	.988	5.809	73.087						
6	.847	4.982	78.070						
7	.701	4.123	82.193						
8	.593	3.489	85.682						
9	.570	3.356	89.038						
10	.493	2.902	91.940						
11	.390	2.294	94.234						
12	.242	1.425	95.659						
13	.212	1.247	96.906						

14	.191	1.122	98.027
15	.160	.943	98.971
16	.100	.585	99.556
17	.075	.444	100.000

Extraction Method: Principal Component Analysis.

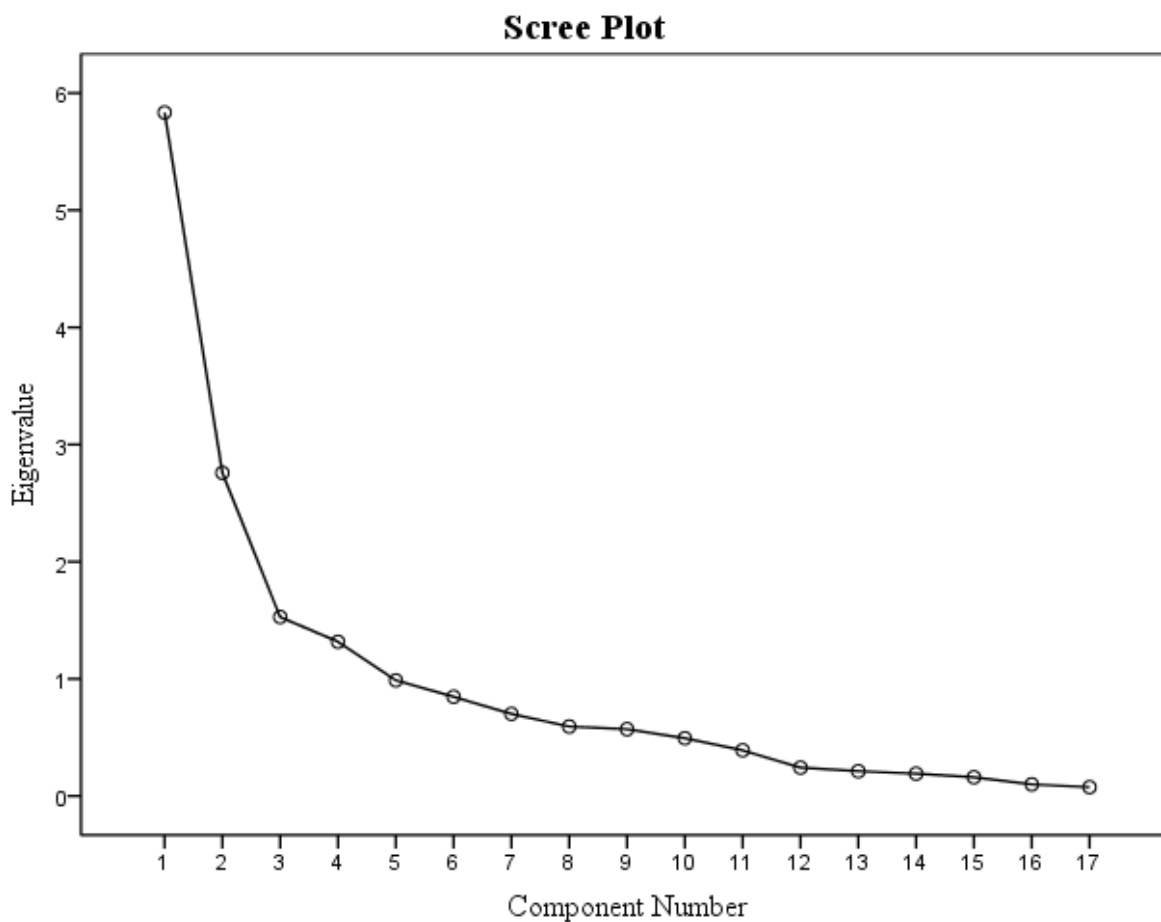


Figure 21 *Scree plot depicting the Eigenvalues of each component of the assessment battery*

The next step is to determine the rotation method in order to carry out the factor analysis. The two main methods of rotation are orthogonal and oblique, with the former assuming uncorrelated factors and the latter assuming correlated factors (Brown, 2009). Tabachnick and Fidell (2007) propose a method of determining the type of rotation by looking at the correlations among factors, which can be obtained through oblique rotation (using SPSS). The authors suggest a .32 cut-off point, so that if the correlations are lower, and therefore not driven by the data, orthogonal rotation would be the method of choice. This criterion was adopted in the factor analysis of this research. Tables 42 and 43 display the

correlations between 4 and 2 components respectively. Overall, it emerged that all correlations were below the .32 value, with the exception of components 1 correlated with 4, which was slightly above (table 42). This suggests the use of orthogonal rotation method to bring out the factor analysis.

Table 42

Component correlation matrix using four components

Component	1	2	3	4
1	1.000	.142	.203	.385
2		1.000	.298	.180
3			1.000	.212
4				1.000

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

Table 43

Component correlation matrix using two components

Component	1	2
1	1.000	.279
2		1.000

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

Finally a component matrix was extracted, where the factor loading of each item on the component was shown. The factors were rotated using *Varimax* rotation, which enables a clearer and less ambiguous interpretation (Yong & Pearce, 2013). The choice of where to

apply a significant loading cut-off point has been examined in the literature. It has been suggested that in determining the reliability of the factor, one could consider the relationship between the factor loading and the sample size, where the larger the sample size, the smaller the allowed factor loadings (Yong & Pierce, 2013). A general cut-off point of .30 seems to be widely accepted (Field, 2009; Whitley & Kite, 2012). However, it has also been recommended to use a factor loading cut-off point of .50, while considering values of between .30 and .49 if there are not enough loadings of .50 and better (Bernard, 2000). This criterion was adopted for the factor analysis of this assessment battery (and questionnaire).

Two component matrices were extracted in relation to the correlation matrices using 4 and 2 components, as indicated in tables 44 and 45 respectively.

Table 44

Rotated component matrix: 4 components

Component

	1 – linguistic stimuli and gaps in noise	2 – dichotic listening	3 – linguistic stimuli and temporal processing	4 – temporal processing
mNWRT(qu)	.708		-.361	
eNWRT(qu)	.752		-.391	
SIT	.859			
mNWRT(n)	.660			
eNWRT(n)	-.572		.416	
Duration Patterns Test (right)			.701	.382
Duration Patterns Test (left)			.597	.320
Frequency Patterns Test (right)				.931
Frequency Patterns Test (left)				.900
Gaps in Noise: Ath (right)	-.426			
Gaps in Noise: % correct (right)			.759	
Gaps in Noise: Ath (left)	-.680			
Gaps in Noise: % correct (left)			.717	
Dichotic Digits focused attention: % correct (right)		-.872		
Dichotic Digits focused attention: % correct (left)		.854		
Dichotic Digits free recall: % correct (right)		-.818		
Dichotic Digits free recall: % correct (left)		.810		

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

Table 45

Rotated component matrix: 2 components

	Component	
	1 : subtests using linguistic stimuli	2 : subtests not using linguistic stimuli
mNWRT(qu)	-.810	
eNWRT(qu)	-.824	
mNWRT(n)	-.712	
eNWRT(n)	-.580	
SIT	.664	
Dichotic Digits focused attention: % correct (right)	.506	
Dichotic Digits focused attention: % correct (left)	.595	
Dichotic Digits free recall: % correct (right)	.573	
Dichotic Digits free recall: % correct (left)	.448	
Duration Patterns Test (right)	.499	.492
Duration Patterns Test (left)	.538	.497
Frequency Patterns Test (right)		.474
Frequency Patterns Test (left)		.618
Gaps in Noise: Ath (right)		-.771
Gaps in Noise: % correct (right)		.866

Gaps in Noise: Ath (left)	-.771
Gaps in Noise: % correct (left)	.859

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Table 44 portrays an attempt to divide the subtests into four components, though not all patterns are defined. While one component is clearly defined, namely component 2 (dichotic listening), other components were found to include subtests which have been documented to test different types of processing. For example, component 1 (linguistic stimuli and gaps in noise) included all the nonword and sentence imitation tasks (all of which use linguistic stimuli), but also included part of a task of temporal processing which incorporates no linguistic elements: the *Gaps in noise* test, analysed only in terms of smallest gap detection (the *Gaps in noise* test analysed in terms of % correct fell under another component). It was also found that three of the nonword repetition tasks correlated positively with component 1, whilst one correlated negatively. This might suggest an inconsistency in the correlations within subtests expected to examine the same skill. The results in table 44 also show that the NWRTs in quiet correlated negatively with component 3 (linguistic stimuli and temporal processing) in addition to their positive correlation with component 1. A reverse pattern was displayed for the English NWRT in noise but not for the Maltese NWRT in noise where only a positive correlation with component 1 emerged.

Table 45 illustrates the subtests divided into two components as recommended from the scree plot result. This division portrayed a more straight forward outcome, separating the subtests into those with linguistic stimuli and those without. All NWRTs correlated negatively with component 1 (subtests using linguistic stimuli), while the Sentence

Imitation Task correlated positively with this component. All dichotic digits subtests also correlated with component 1. On the other hand, all Gaps-in-Noise (GIN) tests and the Frequency Patterns Test correlated with component 2 (subtests not using linguistic stimuli). It emerged that the GIN tests scored through ‘percentage correct’ correlated positively with component 2, while scoring through ‘smallest gap detection’ yielded a negative correlation with the same component.

The Duration Patterns Test loaded on both components suggesting both the use of linguistic and non-linguistic stimuli. A reason for this could be that although the test uses a sequence of tones, the instructions to the children encouraged the interpretation of these tones through linguistic labels i.e. ‘long’ and ‘short’.

5.2.2 Questionnaire of Central Auditory Processing. A factor analysis was also carried out for the questionnaire to determine the relationship between the questions presented. As was mentioned in chapter 3, the aim of the development of this questionnaire was to obtain subjective scores of parents with regard to the perception of their children’s auditory skills. The questionnaire included 20 questions. All questionnaires completed for the study (a total of 131) and additional data (40 questionnaires) obtained with permission (see appendix C, section C - 5) from another project supervised by the researcher (Cassar, 2014) were used for this analysis.

The KMO and Bartlett’s test was computed for the data obtained from the questionnaire, as shown in table 46. The results presented a KMO score above 0.9 and a statistically significant probability value. These values support the use of factor analysis.

Table 46

KMO and Bartlett's test QCAP

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.905
Bartlett's Test of Sphericity	Approx. Chi-Square	1848.414
	df	190
	P-value	0.000

The outcome of the explained variance (as illustrated in table 47) indicated that there is one strong component which alone accounts for 42.28% but a total of 5 components above the eigenvalue of 1. The scree plot (figure 22) portrays clearly that there is one component present above the point of inflection, augmenting the result displayed in table 47.

Table 47

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.497	42.483	42.483	8.497	42.483	42.483	5.779	28.895	28.895
2	1.505	7.526	50.009	1.505	7.526	50.009	2.565	12.824	41.719
3	1.249	6.245	56.255	1.249	6.245	56.255	1.833	9.163	50.882
4	1.171	5.857	62.112	1.171	5.857	62.112	1.721	8.607	59.489
5	1.059	5.293	67.404	1.059	5.293	67.404	1.583	7.916	67.404
6	.863	4.314	71.718						
7	.783	3.916	75.635						
8	.657	3.283	78.918						
9	.589	2.943	81.861						
10	.546	2.729	84.589						
11	.478	2.391	86.980						
12	.414	2.069	89.049						
13	.390	1.949	90.998						

14	.370	1.852	92.850
15	.330	1.648	94.498
16	.306	1.528	96.026
17	.266	1.330	97.356
18	.204	1.021	98.377
19	.180	.902	99.279
20	.144	.721	100.000

Extraction Method: Principal Component Analysis.

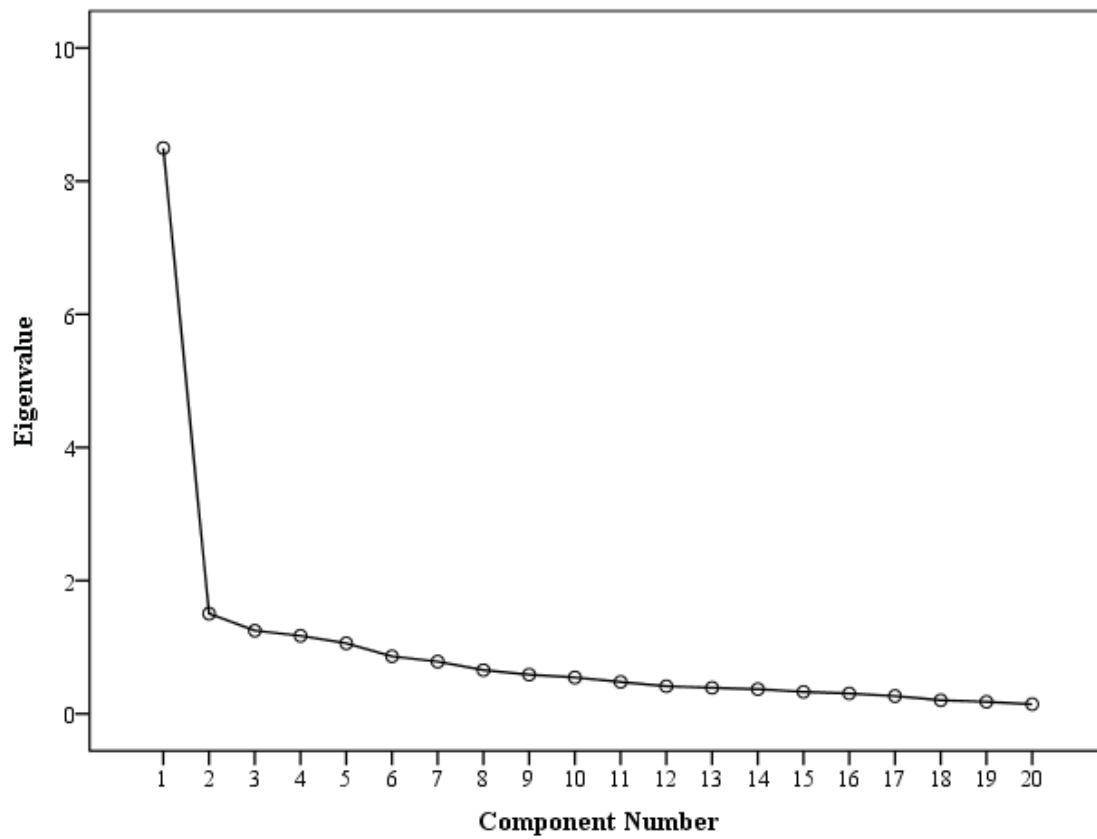


Figure 22 Scree plot depicting the Eigenvalues of each component

The component correlation matrix displayed overall low correlations between components, as shown in table 48 below. Hence orthogonal rotation is recommended (Tabachnick & Fidell, 2007).

Table 48

Component correlation Matrix of the QCAP

Component	1	2	3	4	5
1	1.000	-.281	.362	.258	.337
2		1.000	-.073	-.048	-.131
3			1.000	.210	.224
4				1.000	.159
5					1.000

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

As a result, the rotated component matrix was extracted as shown in table 49, where the factor loading of each item on the component was shown. All items with a loading factor of above .50 are displayed.

Table 49
Rotated Component Matrix of the QCAP

	Component				
	1 : auditory attention and memory	2 : following conversations	3 : sensory stimulation	4 : noisy situations	5 : social aspects
The child finds difficulty listening to speech and understanding it	.632				
The child finds difficulty in attending to a task	.721				
The child is easily distracted	.648				
The child can be forgetful . Specifically for spoken information	.717				
The child has organisational difficulties that cause problems	.674				
The child finds difficulty in following long conversations	.703				
The child finds difficulty in following directions with multiple steps	.757				
The child finds difficulty in taking notes in class	.779				
The child finds difficulty in dividing his/her attention	.689				
The child often finds him/herself unable to keep to task deadlines	.640				

In conversation , the child often asks people to repeat themselves	.576		
The child finds difficulty in following and/or understanding TV programs	.517		
In conversation , the child tends to tilt his/her head towards speakers	.750		
The child finds his/her telephone conversations frustrating	.800		
The child tends to increase the volume of television or audio equipment when listening		.847	
The child seems to be a restless person , who finds great difficulty in keeping still		.587	
The child is sensitive to loud sounds			.848
The child gets distracted in noisy places	.506		.655
The child prefers solitary activities to social activities			.822
The child tends to shy away from class discussions			.611

The component matrix details the results shown by the total variance explained. One strong component emerged in which questions all related to *auditory attention and memory*. Ten questions fell under this component. The other components were less heavily loaded, as was expected from the results obtained through the eigenvalues. The second component incorporated four questions; all related to *following conversations*, while the next three components included two questions each. Component 3 comprised questions related to *sensory stimulation* (auditory and tactile). Component 4 targeted coping in *noisy situations*. One of these questions also cross-loaded to a less extent onto component 1, though this was expected since it touched on *distractibility* in the presence of noise. Finally, component 5 tapped into *social aspects*.

5.3 Descriptive and inferential statistics in terms of demographic factors

The overall descriptive statistics of each subtest, together with the tests of normality for the QCAP were presented in figure 20 and table 38 of section 5.1.1. The same statistical tests were run for each subtest in the assessment battery and are presented in appendix 5, sections C - 1 to C - 3. The descriptive statistics included bringing out the means and standard deviations (SDs) of the participants' performance. The median and interquartile ranges were also presented for each.

In this section, the descriptive statistics of each of the subtests are extracted once again. This time, however, they are divided in terms of their demographic factors:

- age group
- gender
- geographic region (divided into the 'North Western region' (North) and 'South Eastern region' (South) of the island)

- school type
- primary language
- pathology ('no': TD group; 'yes': clinical group) – a small sample (n=30) which included the children with various reported neurodevelopmental disorders was used to compare with the sample of typically developing children. These children were all reported to have listening difficulties and therefore suspected of having an APD

As is shown in section 5.3.1 (QCAP), this includes both illustration, through graphs and boxplots, and tabulated numerical data (in terms of mean, median, standard deviation, interquartile range, and skewness and kurtosis values). For each of the sections that follow (sections 5.3.2 through to 5.3.7) the data are illustrated solely through graphs and boxplots. The reader is referred to appendix 5, section C - 4 for further details of the related tabulated descriptive statistics. Incorporated in each section, the inferential statistics are also presented, depicting the effect of each categorical variable on the performance of each subtest.

5.3.1 Questionnaire of Central Auditory Processing

5.3.1.1 The effect of 'age group' on the QCAP

Boxplot

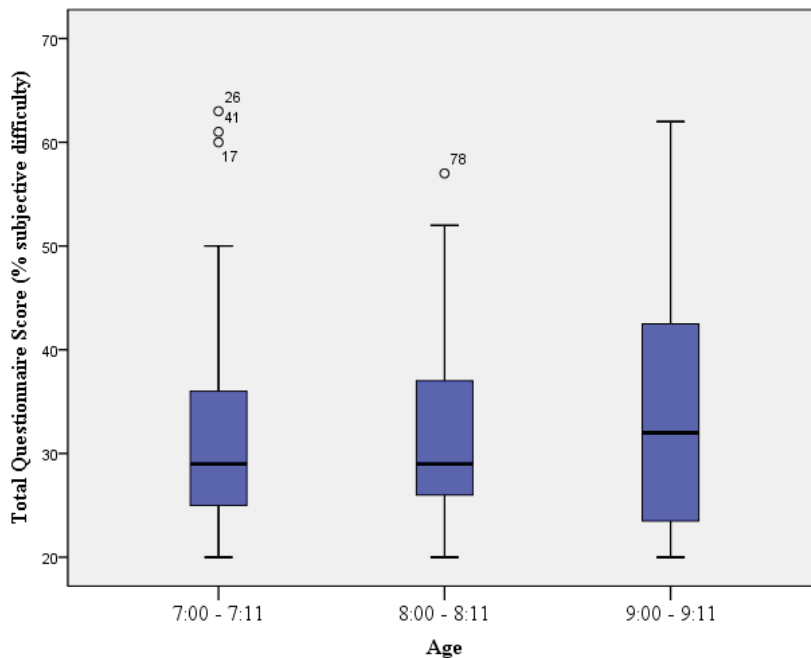


Figure 23 Graphical illustration of the mean QCAP scores categorised by 'age group'

Figure 23 illustrates the median scores across the age groups (7, 8, and 9-year-old children), and is supported by numerical data in table 50. The descriptive statistics indicate a mean score of between 32 and 35. Results also showed that the range of scores obtained by the 9;00-9;11 year olds was larger when compared with the other two age groups.

Table 50

Descriptive statistics: QCAP across age groups

Age	Statistic	Std. Error	z score
-----	-----------	------------	---------

Total Questionnaire Score (% subjective difficulty)	7:00 - 7:11	Mean		32.97	2.013	
		95% Confidence Interval for Mean	Lower Bound	28.87		
			Upper Bound	37.07		
		Median		29.00		
		Std. Deviation		11.564		
		Interquartile Range		12		
		Skewness		1.398	.409	3.41
	Kurtosis		1.344	.798	1.68	
	8:00 - 8:11	Mean		32.22	1.450	
		95% Confidence Interval for Mean	Lower Bound	29.28		
			Upper Bound	35.17		
		Median		29.00		
		Std. Deviation		8.702		
		Interquartile Range		11		
		Skewness		1.111	.393	2.82
	Kurtosis		.907	.768	1.18	
	9:00 - 9:11	Mean		34.81	2.234	
		95% Confidence Interval for Mean	Lower Bound	30.26		
			Upper Bound	39.37		
Median			32.00			
Std. Deviation			12.640			
Interquartile Range			21			
Skewness			.798	.414	1.92	
Kurtosis		-.544	.809	-.67		

Skewness and kurtosis z-scores were generally within the ± 3.29 range suggesting normally distributed data. In contrast, S-W and K-S tests generally indicated non-normally distributed data, even following an attempt at normalisation²² (refer to table 51).

²² The data were log transformed (using the natural log (LN)) in an attempt to normalise the distribution of the skewed data

Table 51

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP categorised by 'age group'

	Age	Kolmogorov-Smirnov ^a Sig.	Shapiro-Wilk Sig.
Total Questionnaire Score (% subjective difficulty)	7:00 - 7:11	.003	.000
	8:00 - 8:11	.000	.000
	9:00 - 9:11	.002	.000
QCAP: after transformation of data	7:00 - 7:11	.059	.009
	8:00 - 8:11	.009	.053
	9:00 - 9:11	.081	.009

a. Lilliefors Significance Correction

A Kruskal-Wallis (K-W) test was conducted to compare the effect of *age group* on the questionnaire score, and resulted in no significant difference between the scores obtained by the three age groups ($H(2) = .689, p = .708$)²³.

5.3.1.2 *The effect of 'gender' on the QCAP*

Boxplot

²³ The parametric equivalent of the K-W test (one-way between subjects ANOVA) was also conducted and found it be in agreement [$F(2,130) = .658, p = .519$].

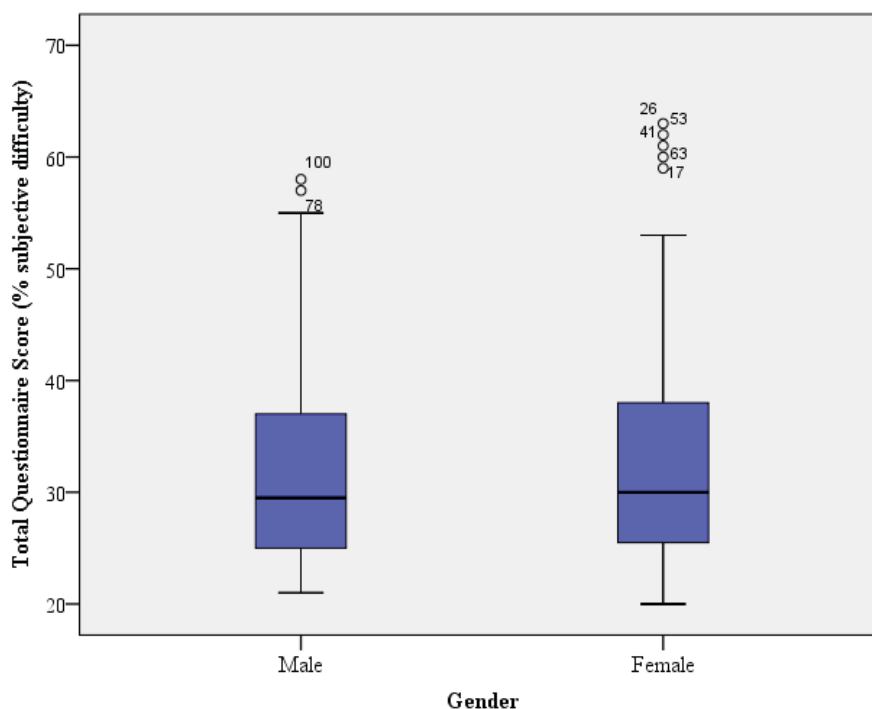


Figure 24 Graphical illustration of the median QCAP scores categorised by ‘gender’

The median scores obtained by the male and female group are illustrated in figure 24. From the boxplot it is evident that the two groups performed similarly. The z-scores drawn out from the skewness and kurtosis values were generally within the ± 3.29 range (except for the skewness score of the female group which was slightly above) (as shown in table 52). Notwithstanding this, the tests of normality still generally indicated data of non-normal distribution (table 53).

The outliers, as highlighted in the box plot, are worth mentioning here. The reader will notice that some outliers emerge across all subtests as they are distributed across their demographic factors. Within this study it was chosen to retain the outliers. Outliers can be categorised into two groups: illegitimate outliers are those likely caused by a known error; legitimate outliers, on the other hand are of an unknown cause (Yang & Berdine, 2016). The outliers in this study would fall under ‘legitimate’, since there is no reason why the score of a few TD children deviates so much from the scores of the rest. The removal of data points on

the basis of statistical analysis when there is no assignable cause is not considered a suitable justification (Yang & Berdine, 2016). Hence, for the sake of avoiding possible data manipulation, outliers were retained.

Table 52

Descriptive statistics: QCAP categorised by 'gender'

	Gender		Statistic	Std. Error	z score	
Total Questionnaire Score (% subjective difficulty)	Male	Mean	32.64	1.587		
		95% Confidence Interval for Mean	Lower Bound	29.44		
			Upper Bound	35.85		
		Median	29.50			
		Std. Deviation	10.283			
		Interquartile Range	13			
		Skewness	1.120	.365	3.06	
	Kurtosis	.453	.717	.63		
	Female	Mean	33.75	1.494		
		95% Confidence Interval for Mean	Lower Bound	30.76		
			Upper Bound	36.74		
		Median	30.00			
		Std. Deviation	11.473			
		Interquartile Range	13			
Skewness		1.141	.311	3.66		
Kurtosis	.559	.613	.91			

Table 53

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP categorised by 'age group'

Gender	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.

Total Questionnaire Score (% subjective difficulty)	Male	.155	59	.001	.866	59	.000
	Female	.162	83	.000	.873	83	.000
QCAP: after transformation of data	Male	.101	59	.200*	.943	59	.008
	Female	.106	83	.021	.942	83	.001

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The Mann-Whitney test showed that although the score obtained by the female group (Mdn=30.00) was slightly greater than the male (Mdn=29.5), the difference was not statistically significant, $U=2421$, $p=.909^{24}$.

5.3.1.3 *The effect of 'geographic region' on the QCAP*

Boxplot

²⁴ The independent samples t-test confirmed this result: $t(140) = -.121$, $p = .904$.

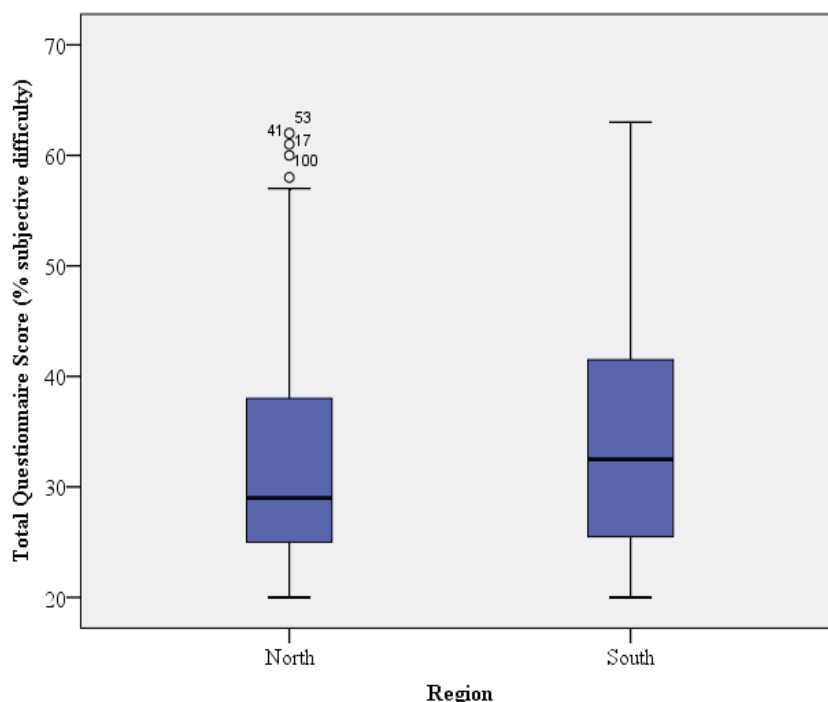


Figure 25 Graphical illustration of the median QCAP scores categorised by ‘geographic region’

Figure 25 demonstrates the median scores obtained by the subjects divided into those living in the north and south of the island. The two groups performed in a similar way (as is shown in the box plot), with the children from the south of Malta displaying a slightly greater median score in the group from the north. The z-scores attained from the skewness and kurtosis values were mainly within the ± 3.29 range (except for the skewness score of the ‘north’ group which was above) (refer to table 54). The K-S and S-W tests of normality generally indicated normally distributed data from the group residing in the South of Malta, but non-normally distributed data from the group living in the North (even following transformation of data) (table 55).

Table 54

Descriptive statistics: QCAP categorised by 'geographic region'

	Region		Statistic	Std. Error	z score		
Total Questionnaire Score (% subjective difficulty)	North	Mean	32.88	1.220			
		95% Confidence Interval for Mean	Lower Bound	30.45			
			Upper Bound	35.31			
		5% Trimmed Mean	32.03				
		Median	29.00				
		Std. Deviation	10.707				
		Interquartile Range	13				
		Skewness	1.220	.274	4.45		
		Kurtosis	.745	.541	1.38		
		South	Mean	34.58	2.421		
			95% Confidence Interval for Mean	Lower Bound	29.57		
				Upper Bound	39.59		
			5% Trimmed Mean	33.85			
			Median	32.50			
			Std. Deviation	11.861			
Interquartile Range	17						
Skewness	.948		.472	2.00			
Kurtosis	.283	.918	0.31				

Table 55

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP categorised by 'geographic region'

	Region	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Total Questionnaire Score (% subjective difficulty)	North	.158	77	.000	.867	77	.000
	South	.153	24	.154	.915	24	.046
QCAP: after transformation of data	North	.114	77	.015	.938	77	.001
	South	.138	24	.200*	.964	24	.531

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

The Mann-Whittney test was performed to investigate whether the difference between the results obtained between the two groups was statistically significant. The result obtained by the 'North' sample (Mdn=29.0) was lower than the 'South' sample (Mdn=32.5). However, the difference was not statistically significant, $U=845$, $p=.528^{25}$.

5.3.1.4 *The effect of 'school type' on the QCAP*

Boxplot

²⁵ The independent samples t-test was in agreement (North (M= 32.88, SD =10.707) and South (M= 34.58, SD=11.861)): $t(99) = -.662$, $p=.509$.

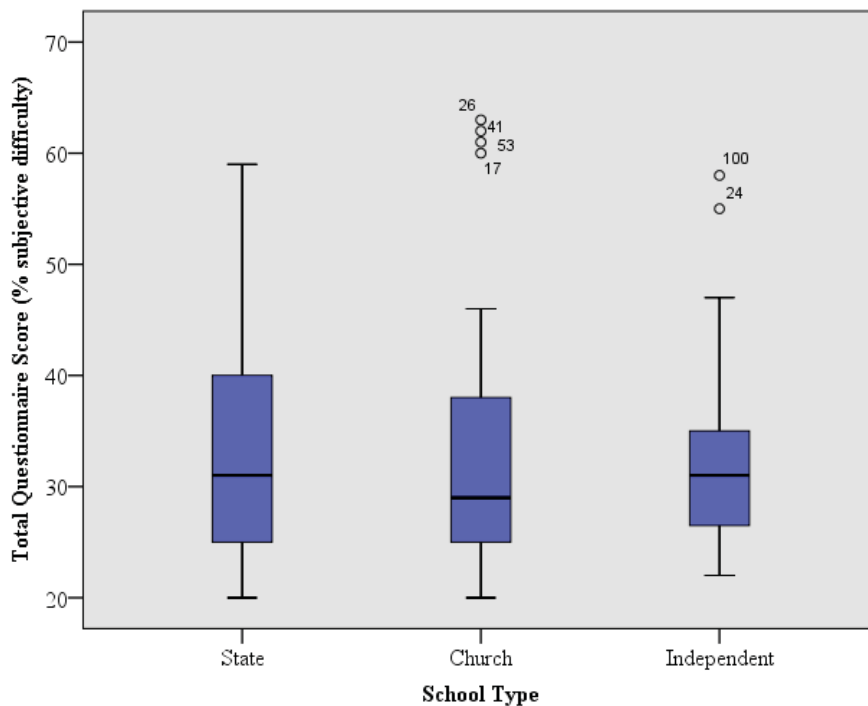


Figure 26 Graphical illustration of the median QCAP scores categorised by 'school type'

The graphical illustrations shown in figure 26 demonstrate that on average, parents of children attending independent schools rated their children as having slightly less listening difficulties in general, followed by church and then state schools. Nevertheless, the boxplots display long whisker lines denoting a variation in scores across all school types. Outliers emerged in the two groups of a smaller sample size (the church and independent school types). However, these scores are similar to some obtained from the state school sample, as illustrated through the longest whisker line of this school type.

Table 56

Descriptive statistics: QCAP categorised by 'school type'

School Type		Statistic	Std. Error	z score
Total Questionnaire Score (% subjective difficulty)	State	Mean	33.54	1.709
		95% Confidence Interval for Mean	Lower Bound	30.08
			Upper Bound	36.99
		5% Trimmed Mean	32.91	
		Median	31.00	
		Std. Deviation	10.941	
		Interquartile Range	16	
	Skewness	.808	.369	2.19
	Kurtosis	-.401	.724	.55
	Church	Mean	33.33	2.016
		95% Confidence Interval for Mean	Lower Bound	29.24
			Upper Bound	37.43
		5% Trimmed Mean	32.45	
		Median	29.00	
Std. Deviation		12.097		
Interquartile Range		13		
Skewness	1.356	.393	3.45	
Kurtosis	1.084	.768	1.41	
Independent	Mean	32.79	1.942	
	95% Confidence Interval for Mean	Lower Bound	28.77	
		Upper Bound	36.81	
	5% Trimmed Mean	32.01		
	Median	31.00		
	Std. Deviation	9.514		
	Interquartile Range	9		

	Skewness	1.399	.472	1.51
	Kurtosis	1.702	.918	1.85

The skewness and kurtosis z scores were generally within the ± 3.29 range, with the exception of the church school skewness result which was slightly above as is seen in table 57. The K-S and S-W tests of normality displayed varying results. The K-S test indicated a normal distribution in the ‘state school’ data only, while the S-W test suggested data of a non-normal distribution across all school group samples. Following normalisation of the data both K-S and S-W tests suggested normally distributed data for both ‘state’ and ‘independent’ school groups, but not for the ‘church’ school group (table 57).

Given this mixed results in terms of data normality, both the Kruskal-Wallis test was conducted to analyse the effect of *school type* on the QCAP score, and whether the differences were statistically significant. The K-W showed no significant difference between the scores obtained by the three school types ($H(2) = .082, p = .960$)²⁶.

Table 57

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP categorised by ‘school type’

School Type	Kolmogorov-Smirnov ^a	Shapiro-Wilk
-------------	---------------------------------	--------------

²⁶ The ANOVA was in agreement [$F(2,98) = .035, p = .966$].

		Statistic	df	Sig.	Statistic	df	Sig.
Total Questionnaire Score (% subjective difficulty)	State	.133	41	.067	.907	41	.003
	Church	.192	36	.002	.834	36	.000
	Independent	.199	24	.015	.861	24	.004
QCAP: after transformation of data	State	.113	41	.200*	.947	41	.056
	Church	.146	36	.049	.923	36	.015
	Independent	.143	24	.200*	.934	24	.122

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

5.3.1.5 *The effect of 'primary language' on the QCAP*

Boxplot

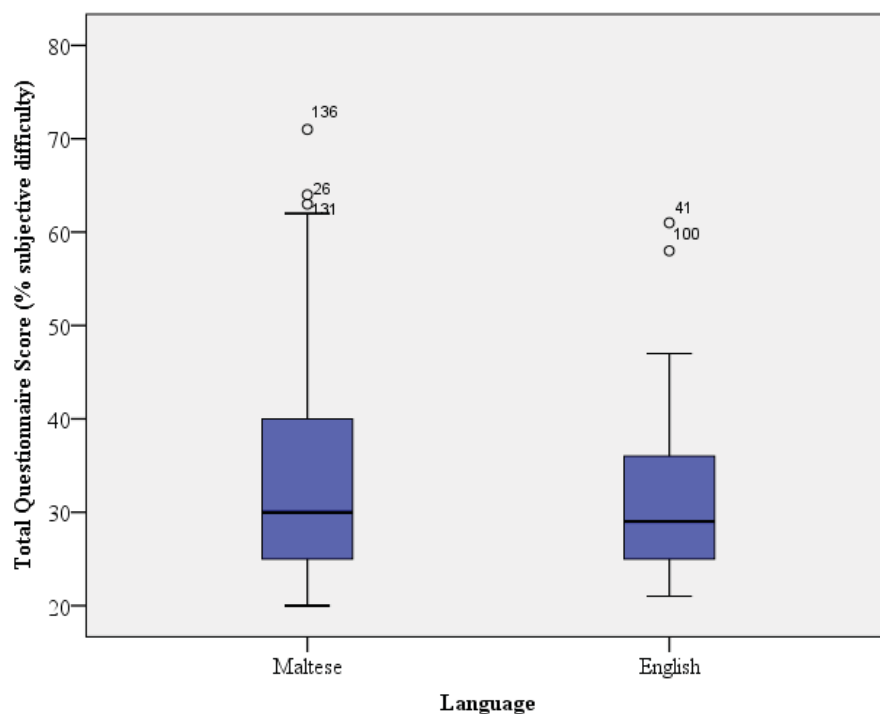


Figure 27 Graphical illustration of the median QCAP scores categorised by ‘primary language’

The descriptive statistics (as explained in figure 27 and table 58) show similar scores between the two groups. The parents of children who used English as their primary language (PL) overall scored lower, indicating slightly less listening difficulties. The box plot also reveals less variation in the scores given to the ‘English’ PL group. Having mentioned this, it must be kept in mind that, similarly to the primary language distribution in Malta, the number of children forming the ‘English’ PL group was less than the ‘Maltese’ PL group (refer to distribution in tables 3 and 4 of chapter 3: Methodology). This distribution may have an influence on these results.

Both groups exhibited skewness z scores of over ± 3.29 , suggesting data of non-normal distribution. The K-S and S-W tests (table 59) also generally indicated data of non-normal distribution, even following attempts at transforming the data, in which case only the K-S test of the English PL group emerged as normally distributed data.

Table 58

Descriptive statistics: QCAP categorised by 'primary language'

Language		Statistic	Std. Error	z score	
Total Questionnaire Score (% subjective difficulty)	Maltese	Mean		33.66	1.276
		95% Confidence Interval for Mean	Lower Bound	31.12	
			Upper Bound	36.19	
		5% Trimmed Mean	32.71		
		Median	30.00		
		Std. Deviation	12.310		
		Interquartile Range	16		
		Skewness	1.129	.250	4.516
		Kurtosis	.506	.495	1.022
		English	Mean	31.61	1.323
	95% Confidence Interval for Mean		Lower Bound	28.95	
			Upper Bound	34.27	
	5% Trimmed Mean		30.75		
	Median	29.00			
Std. Deviation	9.262				
Interquartile Range	12				
Skewness	1.363	.340	4.00		
Kurtosis	1.756	.668	2.62		

Table 59

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP categorised by 'primary language'

Language	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.

Total	Maltese	.156	93	.000	.879	93	.000
Questionnaire Score (% subjective difficulty)	English	.142	49	.015	.871	49	.000
QCAP: after transformation of data	Maltese	.091	93	.056	.943	93	.001
	English	.105	49	.200*	.938	49	.012

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The Mann-Whitney did not reveal a statistically significant difference, $U=2190.5$, $p=.705$ between the Maltese ($Mdn=30$) and the English ($Mdn=29$) PL groups²⁷.

5.3.1.6 *The effect of 'pathology' (TD versus clinical groups) on the QCAP*

Boxplot

²⁷ The independent samples t-test was in agreement (Maltese ($M= 33.66$, $SD =12.3$) and English ($M= 31.61$, $SD=9.3$)): $t(140)=1.02$, $p=.310$.

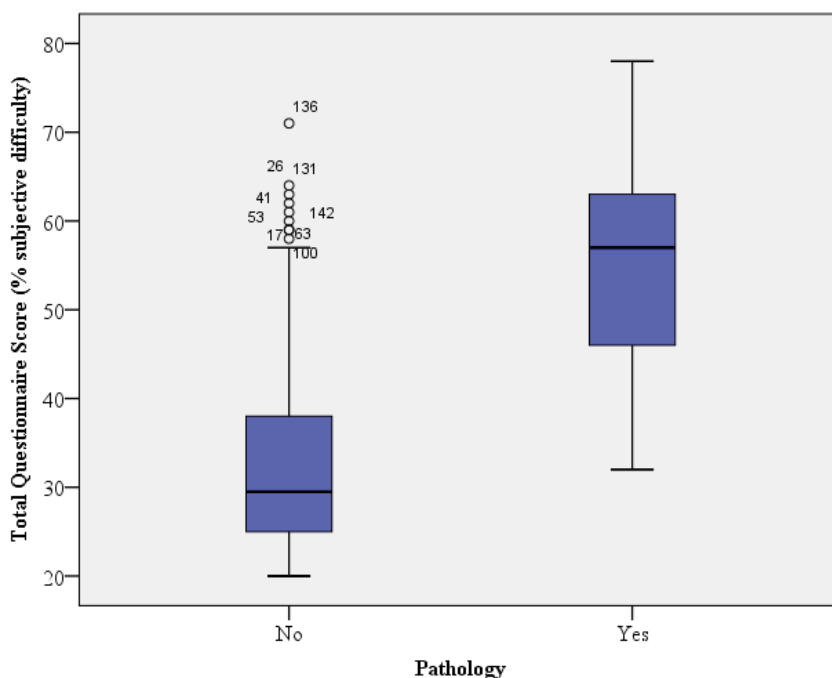


Figure 28 Graphical illustration of the median QCAP scores across ‘pathology’
(TD versus clinical group)

Figure 28 clearly indicates a substantial difference between the questionnaire scores of the two groups. While the TD subjects obtained a mean score of 32.95 (table 60), the clinical group presented with a mean score of 54.45 indicating a parental perceptions of greater listening difficulties.

The TD group exhibited skewness z scores of over ± 3.29 , indicating data of non-normal distribution. On the other hand the data obtained from the ‘pathology’ group resulted in skewness and kurtosis z scores within the ± 3.29 range, signifying normally distributed data. The K-S and S-W test results (table 61) were in agreement of the skewness / kurtosis scores.

Table 60

Descriptive statistics: QCAP categorised by 'pathology'

	Pathology		Statistic	Std. Error	z score		
Total Questionnaire Score (% subjective difficulty)	No	Mean	32.95	.953			
		95% Confidence Interval for Mean	Lower Bound	31.07			
			Upper Bound	34.84			
		5% Trimmed Mean	32.00				
		Median	29.50				
		Std. Deviation	11.359				
		Range	51				
		Interquartile Range	13				
		Skewness	1.238	.203	6.10		
		Kurtosis	.952	.404	2.36		
		Yes	Mean	54.45	2.378		
			95% Confidence Interval for Mean	Lower Bound	49.58		
				Upper Bound	59.32		
			5% Trimmed Mean	54.37			
	Median		57.00				
	Std. Deviation		12.805				
	Range	46					
	Interquartile Range	18					
	Skewness	.081	.434	0.19			
	Kurtosis	-.798	.845	-0.944			

Table 61

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP categorised by 'pathology'

	Pathology	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Total Questionnaire Score (% subjective difficulty)	No	.153	142	.000	.874	142	.000
	Yes	.119	29	.200*	.971	29	.597
QCAP: after transformation of data	No	.097	142	.002	.945	142	.000
	Yes	.136	29	.182	.965	29	.433

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

In both the Mann-Whittney test and the independent samples t-test, a statistically significant difference was found between the two groups:

- Mann-Whittney: $U=431.5$, $p<.001$ between the TD ($Mdn=29.5$) and the clinical ($Mdn=57.0$) groups.
- Independent samples t-test: TD ($M= 32.95$, $SD =11.36$) and clinical ($M= 54.45$, $SD=12.80$) groups: $t(168)= -9.09$, $p<.001$.

Further analysis was carried out to investigate whether the difference between the groups is evident in all the emerged factors described in section 5.2.2. Figure 29 reveals a substantial difference in scores between groups related to 'attention and memory', 'conversation skills', 'sensory stimulation' and 'noise', indicating that the children forming the clinical group were reported to exhibit greater difficulties in these areas. A difference, but to a lesser extent, was also evident in the questions related to 'social skills'. These results are further explained in table 62.

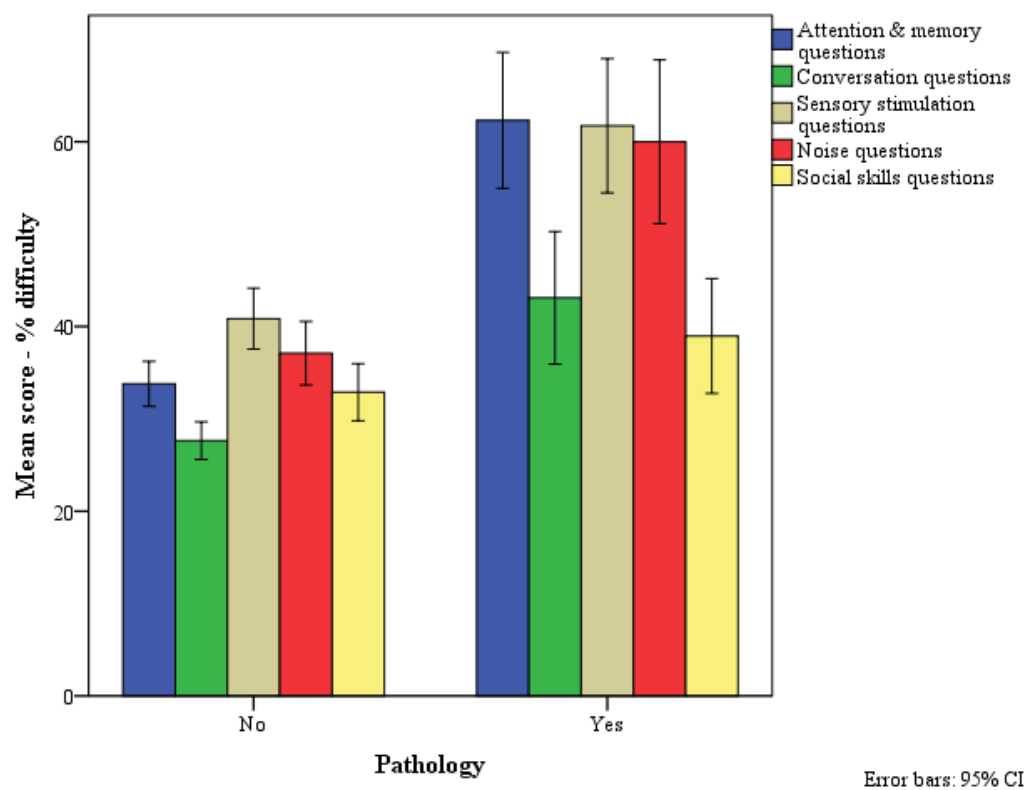


Figure 29 Graphical illustration of the mean QCAP scores categorised by ‘pathology’ (TD versus clinical group) in terms of the emerged factors

Table 62

Descriptive statistics: QCAP categorised by ‘pathology’ in terms of the emerged factors

% difficulty	Pathology	Statistic	Std. Error	z score
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Attention & memory questions	No	Mean		33.7900	1.23197	
		95% Confidence Interval for Mean	Lower Bound	31.3545		
			Upper Bound	36.2255		
		Std. Deviation		14.68061		
		Range		69.09		
		Interquartile Range		16.36		
		Skewness		1.544	.203	7.60
		Kurtosis		2.130	.404	5.27
	Yes	Mean		62.3152	3.593	
		95% Confidence Interval for Mean	Lower Bound	54.9545		
			Upper Bound	69.6758		
		Std. Deviation		19.35086		
		Range		69.09		
		Interquartile Range		35.45		
Skewness			-.006	.434	-0.01	
Kurtosis			-1.260	.845	-1.49	
Conversation questions	No	Mean		27.6408	1.028	
		95% Confidence Interval for Mean	Lower Bound	25.6073		
			Upper Bound	29.6744		
		Std. Deviation		12.25749		
		Range		70.00		
		Interquartile Range		10.00		
		Skewness		2.300	.203	11.33
		Kurtosis		6.124	.404	15.16
	Yes	Mean		43.1034	3.504	
		95% Confidence Interval for Mean	Lower Bound	35.9255		
			Upper Bound	50.2814		
		Range		65.00		
		Interquartile Range		30.00		
		Skewness		.638	.434	1.47
Kurtosis			-.463	.845	-0.55	
Sensory stimulation		No	Mean		40.85	1.665
	95% Confidence Interval		Lower Bound	37.55		

questions		for Mean	Upper Bound	44.14		
		Std. Deviation		19.840		
		Range		80		
		Interquartile Range		30		
		Skewness		.932	.203	4.59
		Kurtosis		.351	.404	0.87
	Yes	Mean		61.72	3.547	
		95% Confidence Interval for Mean	Lower Bound	54.46		
			Upper Bound	68.99		
		Std. Deviation		19.099		
		Range		80		
		Interquartile Range		20		
		Skewness		-.066	.434	-0.15
	Kurtosis		.232	.845	0.27	
Noise questions	No	Mean		37.1127	1.741	
		95% Confidence Interval for Mean	Lower Bound	33.6700		
			Upper Bound	40.5553		
		Std. Deviation		20.75118		
		Range		80.00		
		Interquartile Range		30.00		
		Skewness		1.026	.203	5.05
		Kurtosis		-.077	.404	-0.19
	Yes	Mean		60.0000	4.32	
		95% Confidence Interval for Mean	Lower Bound	51.1374		
			Upper Bound	68.8626		
		Std. Deviation		23.29929		
		Range		80.00		
	Interquartile Range		40.00			
	Skewness		.255	.434	0.59	
	Kurtosis		-.743	.845	0.88	
Social skills questions	No	Mean		32.8873	1.56	
		95% Confidence Interval for Mean	Lower Bound	29.7973		
			Upper Bound	35.9774		

		Std. Deviation	18.62588		
		Range	80.00		
		Interquartile Range	20.00		
		Skewness	1.708	.203	8.41
		Kurtosis	2.614	.404	6.47
Yes		Mean	38.9655	3.03	
		95% Confidence Interval for Mean	Lower Bound	32.7530	
			Upper Bound	45.1780	
		Std. Deviation	16.33245		
		Range	60.00		
		Interquartile Range	15.00		
		Skewness	.865	.434	1.99
		Kurtosis	.399	.845	0.47

The data distribution following the division into factors remained non-normal for the TD group and varied across factors in the ‘pathology’ group (refer to the skewness/kurtosis values in table 62 and the tests of normality in table 63).

Table 63

Kolmogorov Smirnov and Shapiro-Wilk values: QCAP categorised by ‘pathology’ in terms of the emerged factors

	Pathology	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Attention & memory questions	No	.198	142	.000	.829	142	.000
	Yes	.171	29	.030	.937	29	.085
Attention & memory questions: after transformation of data	No	.116	142	.000	.922	142	.000
	Yes	.133	29	.200*	.931	29	.060

Conversation questions	No	.275	142	.000	.675	142	.000
	Yes	.115	29	.200*	.927	29	.045
Conversation questions: after transformation of data	No	.277	142	.000	.761	142	.000
	Yes	.121	29	.200*	.948	29	.166
Sensory stimulation questions	No	.180	142	.000	.883	142	.000
	Yes	.160	29	.056	.958	29	.290
Sensory stimulation questions: after transformation of data	No	.173	142	.000	.910	142	.000
	Yes	.220	29	.001	.898	29	.009
Noise questions	No	.253	142	.000	.800	142	.000
	Yes	.155	29	.072	.936	29	.080
Noise questions: after transformation of data	No	.283	142	.000	.822	142	.000
	Yes	.196	29	.006	.934	29	.072
Social skills questions	No	.270	142	.000	.729	142	.000
	Yes	.268	29	.000	.868	29	.002
Social skills questions: after transformation of data	No	.306	142	.000	.789	142	.000
	Yes	.224	29	.001	.890	29	.006

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Through the Mann-Whitney test, it emerged that the differences between groups in all subtests was statistically significant (table 64)²⁸.

²⁸ The independent samples t-test was in agreement for all factors, with the exception of 'social skills', suggesting that this difference is not substantial enough to be statistically significant. But since the data collected on 'social skills' for both groups were not normally distributed, the results from the Mann-Whitney test were considered.

Table 64

Comparison of means between the two groups categorised by 'pathology'

% difficulty	Mann-Whitney test				t-test for Equality of Means						
	U	W	z	p	t	df	p	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
										Lower	Upper
Attention & memory	480.5	10633.5	-6.512	<.001	-7.51	34.87	.00	-28.53	3.80	-36.24	-20.81
Conversation	943.5	11096.5	-4.826	<.001	-4.23	32.99	.00	-15.46	3.65	-22.89	-8.03
Sensory stimulation	887.0	11040	-4.891	<.001	-5.196	169	.000	-20.879	4.018	-28.811	-12.947
	921.5	11074.5	-4.843	<.001	-5.299	169	.000	-22.88732	4.31896	-31.41338	-14.36127
Social skills	1470	11623	-2.572	.010	-1.633	169	.104	-6.07819	3.72215	-13.42609	1.26971

5.3.2 Sub-tests using linguistic content: Maltese and English nonword

repetition tests in noise

5.3.2.1 *The effect of 'age group' on the nonword repetition tests in noise*

Boxplot

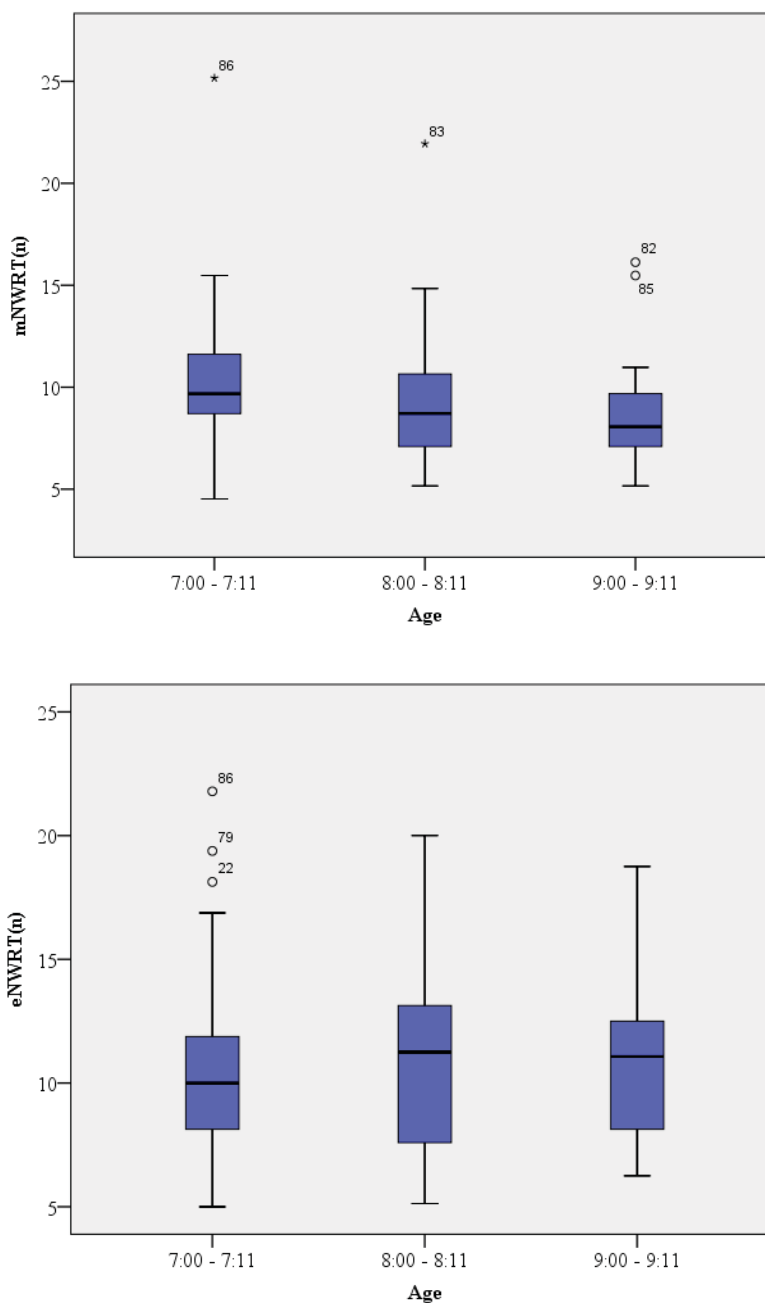


Figure 30 Graphical illustration of the median NWRT % error scores categorised by 'age group'

The three age groups were found to perform similarly in the Maltese- and English-based NWRT as is illustrated in figure 30. It also emerged that there was greater variability in the percentage error scores of the eNWRT. The skewness and kurtosis z scores (appendix C, table 13) were found to be greater than ± 3.29 in all age groups of the mNWRT but within this range for the eNWRT, suggesting that the data results from the latter test were more normally distributed.

The K-S and S-W (appendix C table 14) tests of normality also indicated generally more normally distributed data in the eNWRT. However, following normalisation of the data both subtests resulted in a normal distribution.

An ANOVA using the normalised data was run to compare the effect of age on the percentage error scores. The result showed no statistically significant difference between groups of both subtests [mNWRT(n): $[F(2,96) = 2.511, p = .087]$; eNWRT(n): $[F(2,95) = 0.302, p = .740]$].

5.3.2.2 *The effect of 'gender' on the nonword repetition tests in noise*

Boxplot

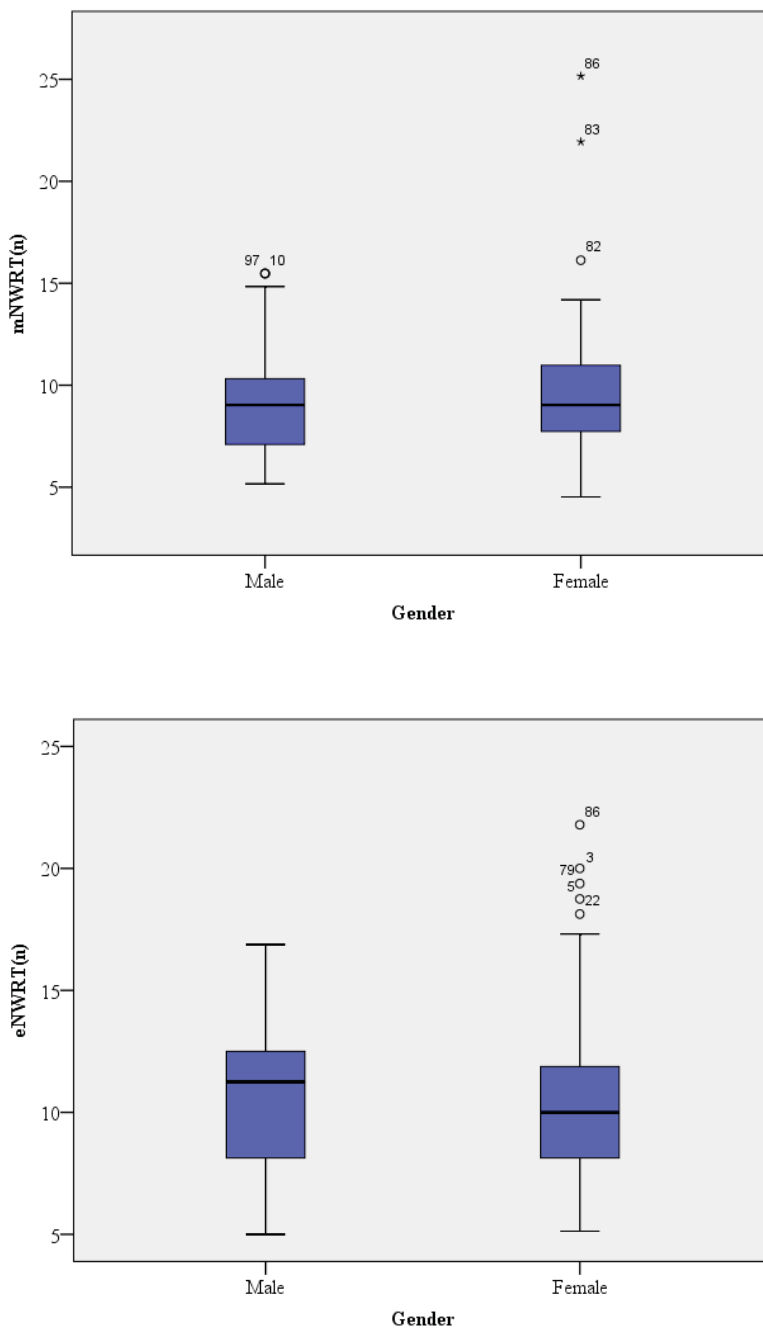


Figure 31 Graphical illustration of the median NWRT % error scores categorised by 'gender'

The two groups were found to obtain similar results on both subtests (refer to figure 31 and appendix C table 15). The skewness and kurtosis z scores were within the ± 3.29 range in the 'male' group but generally outside this range in the 'female' group, suggesting the data results collected from the males were more normally distributed. The K-S and S-W tests of normality demonstrated data of generally a non-normal distribution (with the exception of the results obtained by the 'male' group in the eNWRT, as demonstrated in appendix C table 16). Following normalisation of the data the K-S and S-W tests resulted in overall normally distributed data (excluding the eNWRT 'male' group results).

The Mann-Whitney test was performed using the original (not transformed) data and did not expose a statistically significant difference on either subtest of NWRT, (mNWRT(n): $U=1149.5$, $p=.779$ between the 'male' (Mdn=9.03) and the 'female' (Mdn=9.03) groups; eNWRT(n): $U=1036$, $p=.339$ between the 'male' (Mdn=11.25) and the 'female' (Mdn=10.0) groups)²⁹.

²⁹ The parametric equivalent, computed using the normalised data, brought out the same result (mNWRT: male ($M=9.17$, $SD=2.80$) and female ($M=9.68$, $SD=3.64$): $t(98)=-.593$, $p=.554$; eNWRT: male ($M=10.94$, $SD=3.17$) and female ($M=10.71$, $SD=3.87$): $t(96)=.500$, $p=.618$

5.3.2.3 The effect of 'geographic region' on the nonword repetition tests in noise

Boxplot

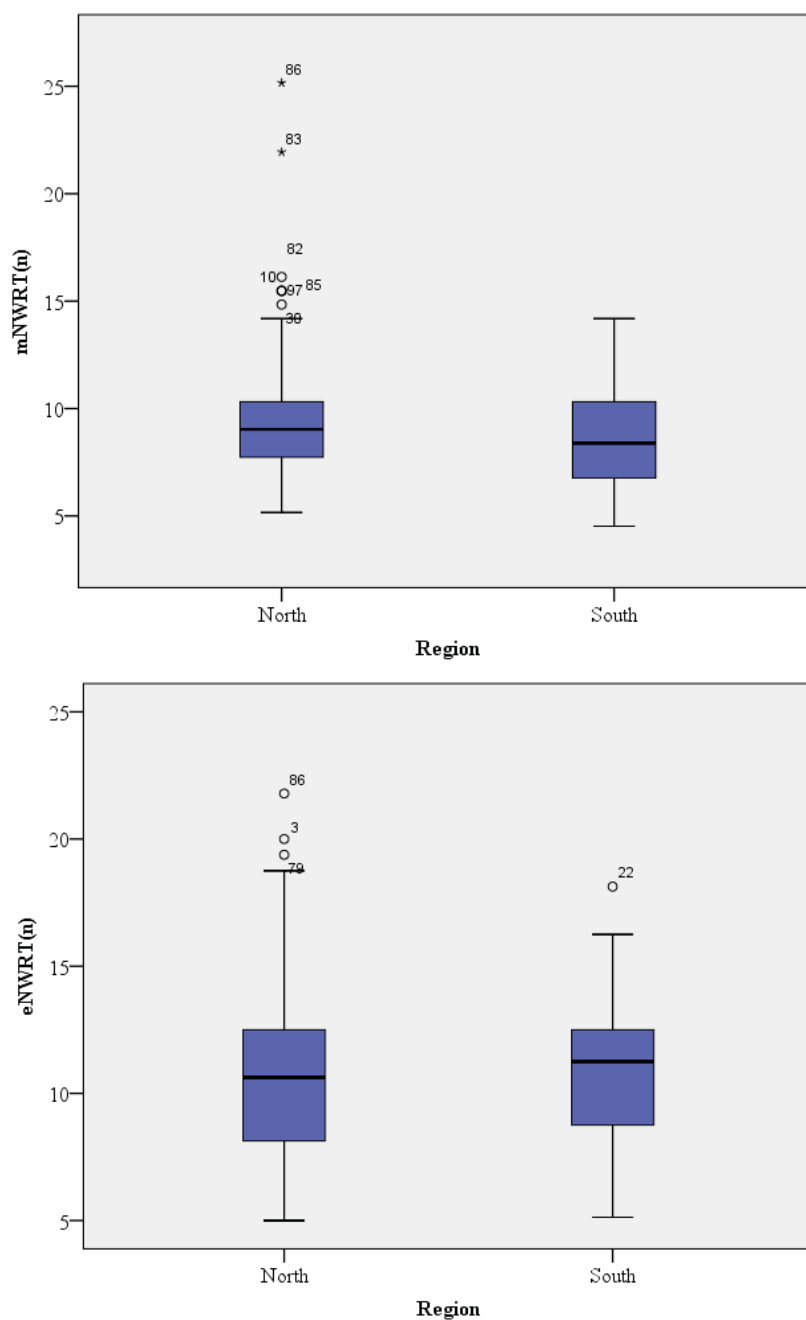


Figure 32 Graphical illustration of the median NWRT % error scores categorised by 'geographic region'

The subjects living in the North and South of the island were also found to perform similarly as is demonstrated in the box plot of figure 32, with the median error score

from the ‘South’ group being slightly less than the ‘North’ group. The skewness and kurtosis z scores (appendix C table 17) indicate that the data obtained from the ‘South’ group are more normally distributed for both subtests. This result was consistent with the K-S and S-W tests of normality (appendix C table 18). Following normalisation of the data the K-S and S-W test exhibited overall normally distributed data with the exception of the ‘North’ group performance in the mNVRT(n).

Given the variability in the distribution of the data between groups, both parametric and non-parametric tests were carried out, with the non-parametric results presented in text. No statistically significant difference between the two groups emerged in both subtests:

mNVRT

- Mann-Whitney: $U=818.0$, $p=.502$ between the ‘North’ (Mdn=9.03) and the ‘South’ (Mdn=8.39) groups.

eNVRT

- Mann-Whitney: $U=864.5$, $p=.846$ between the ‘North’ (Mdn=10.63) and the ‘South’ (Mdn=11.25) groups³⁰.

5.3.2.4 *The effect of ‘school type’ on the nonword repetition tests in noise*

Boxplot

³⁰ Parametric equivalent (independent samples t-test):

mNNVRT(n): ‘North’ (M= 9.70, SD =3.52) and ‘South’ (M= 8.74, SD=2.47) groups: $t(97)= 1.208$, $p=.230$

eNVRT(n): ‘North’ (M= 10.84, SD =3.69) and ‘South’ (M= 10.71, SD=3.27) groups: $t(96)= -.142$, $p=.884$

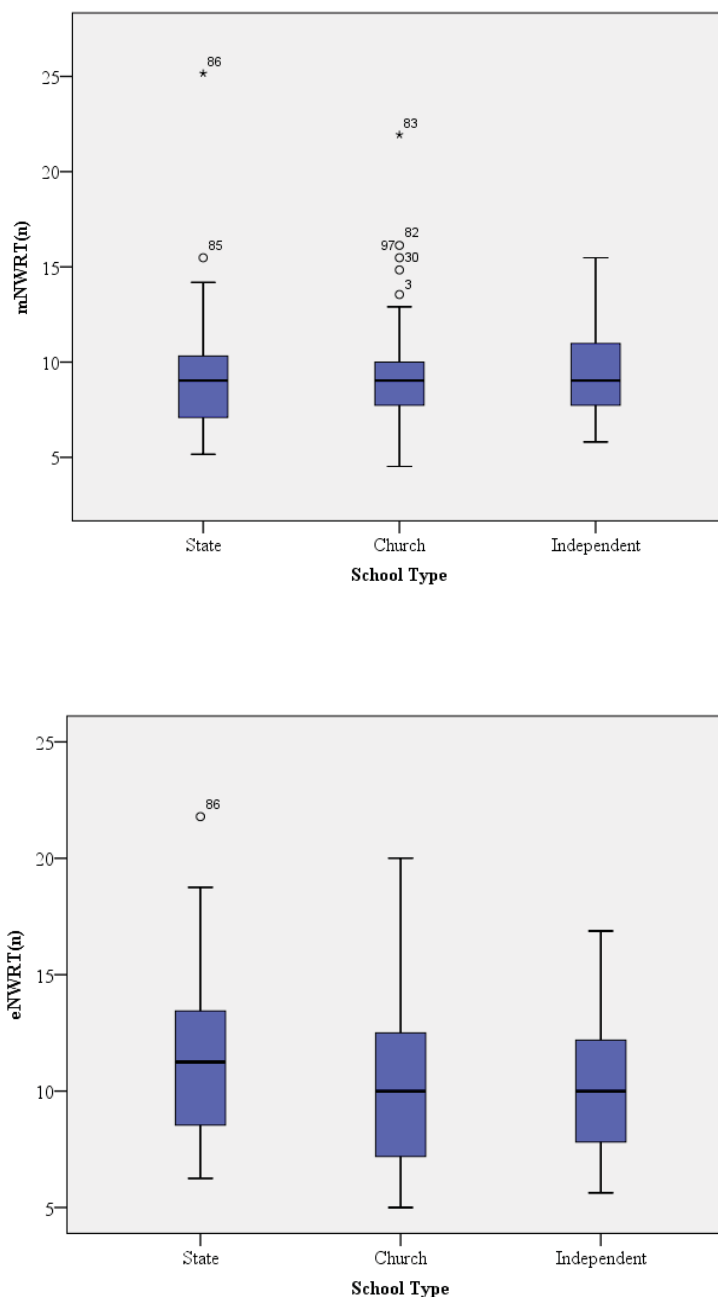


Figure 33 Graphical illustration of the median NWRT % error scores categorised by 'school type'

Comparable with the previous groups, children attending the different school types performed similarly in both subtests (refer to the box plots of figure 33 and the descriptive statistics in appendix C table 19). The children attending state schools on average obtained a lower percentage error score on the mNWRT when compared to the children attending church and independent schools. While the opposite was observed for the eNWRT. This is

not surprising when considering that the majority of children attending state schools were primarily Maltese speaking, while those attending the other schools were primarily English speaking or balanced between both languages (refer to tables 3.3 and 3.4 of chapter 3: Methodology).

The tests of normality (appendix C table 20) presented variability of the data distribution between groups. Data normalisation subsequently gave rise to normally distributed results.

An ANOVA using the normalised data was run to compare the effect of school type on the percentage error scores. The result showed no statistically significant difference between groups of both subtests [mNWRT(n): $F(2,96) = .278, p = .758$; eNWRT(n): $F(2,95) = 1.528, p = .222$].

5.3.2.5 *The effect of 'primary language' on the nonword repetition tests in noise*

Boxplot

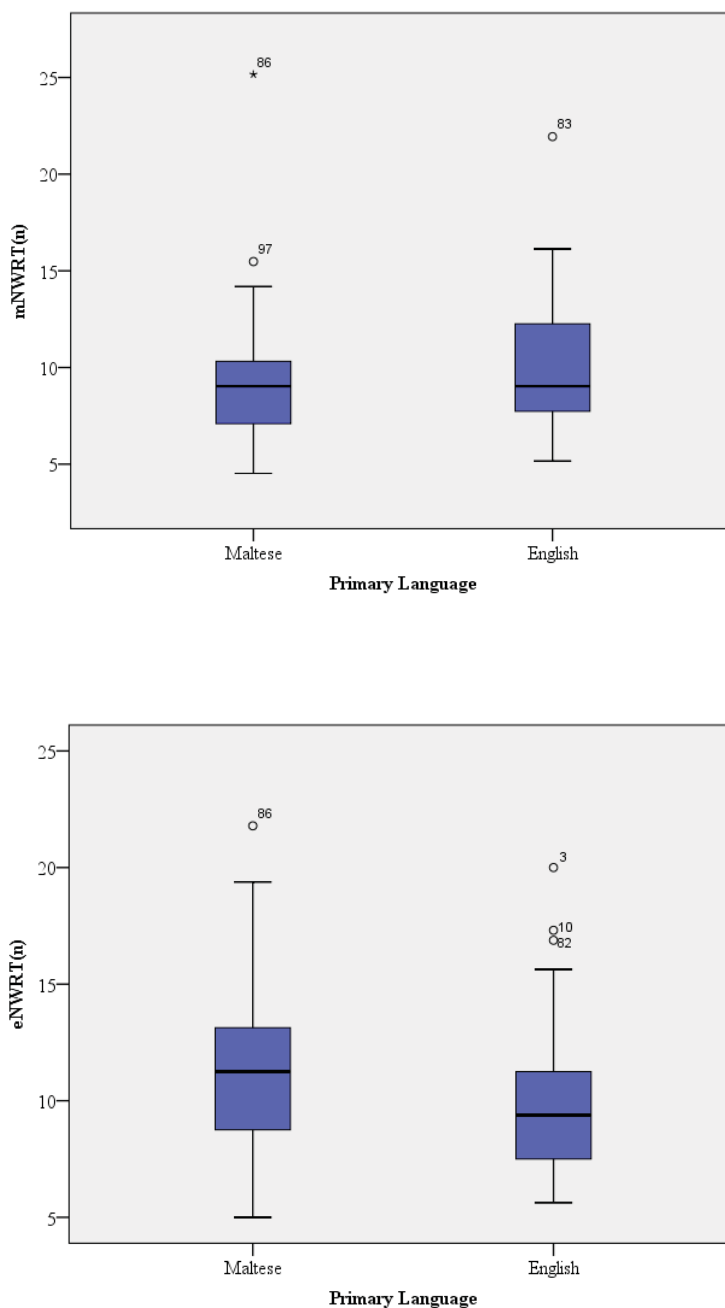


Figure 34 Graphical illustration of the median NWRIT % error scores categorised by 'primary language'

On average, those children whose PL was Maltese obtained a lower percentage error score in the mNWRIT than the PL English group. The opposite was evident in the eNWRIT. Nonetheless, the box plots suggest that the difference in scores is only slight and a substantial

amount of overlap in the scores of the two groups is apparent, as is also described through the descriptive statistics (appendix C table 21).

The tests of normality suggested mainly data of non-normal distribution (appendix C table 22), while transformation of the data resulted in a predominantly normal distribution. The independent samples t-test was performed using the normalised data to evaluate the effect of PL on the percentage error scores in each subtest. The result showed no statistically significant difference between groups [mNWRT(n): 'PL Maltese' (M= 9.04, SD =3.06) and 'PL English' (M= 10.06, SD=3.58) groups: $t(97) = -1.530$, $p = .129$; eNWRT(n): 'PL Maltese' (M= 11.32, SD =3.69) and 'PL English' (M= 10.09, SD=3.32) groups: $t(96) = -1.630$, $p = .107$].

5.3.2.6 *The effect of 'pathology' (TD versus clinical groups) on the nonword repetition tests in noise*

Boxplot

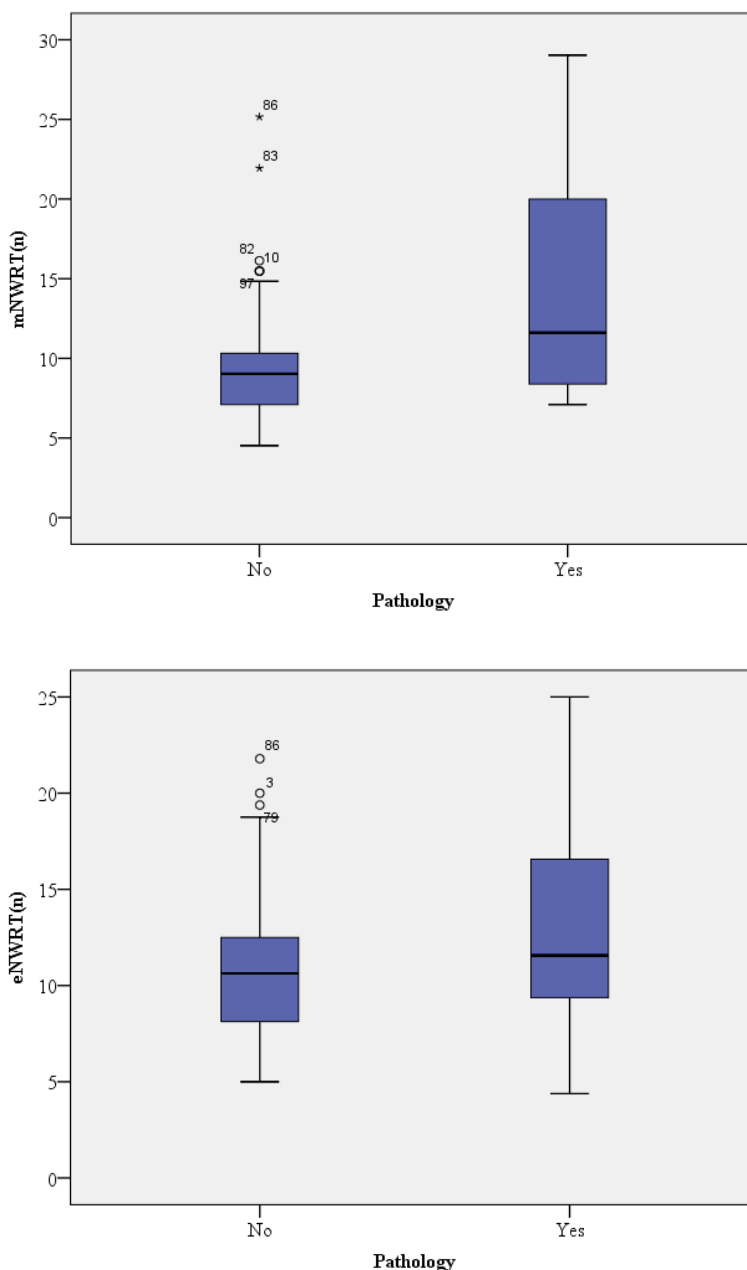


Figure 35 Graphical illustration of the median NWRT % error scores categorised by ‘pathology’ (TD versus clinical group)

The mean percentage error scores exhibited by the two groups demonstrates a difference in performance, with the TD group scoring on average lower percentage errors than the clinical group. The box plots also display a greater variation in the performance of the latter group, with an evident overlap between scores of the two groups in both subtests.

The K-S and S-W tests suggested predominantly data of non-normal distribution (appendix C table 24). Following 'Ln' transformation of the data, mostly normal distribution was obtained. The independent samples t-test was performed using the normalised data to evaluate the effect of 'pathology' on the percentage error scores in each subtest. The result showed a statistically significant difference between the two groups in the mNWRT(n): 'TD group' (M= 9.47, SD =3.31) and 'pathology' group (M= 14.19, SD=6.72) groups: $t(121) = -4.674, p < .001$. The same pattern did not emerge in the eNWRT(n) where no statistically significant difference was found between the two groups: 'TD group' (M= 10.80, SD =3.58) and 'clinical group (M= 12.76, SD=5.73) groups: $t(120) = -1.483, p = .141$.

5.3.2.7 *Comparison between the Maltese and English NWRT tests in noise.*

In the previous sections, the inferential statistics administered on the Maltese and English NWRTs in noise on subjects divided into demographic factors, showed no statistically significant differences between groups across all variables involving the TD subjects. A statistically significant difference emerged between the performance of the of the TD and clinical groups in the mNWRT(n). Following these results it is of interest to explore whether there are any differences in performance of each group in the two subtests. Figure 36 displays the mean percentage error scores obtained by the TD group on the two subtests. It demonstrates that overall these children performed better in the Maltese subtest.

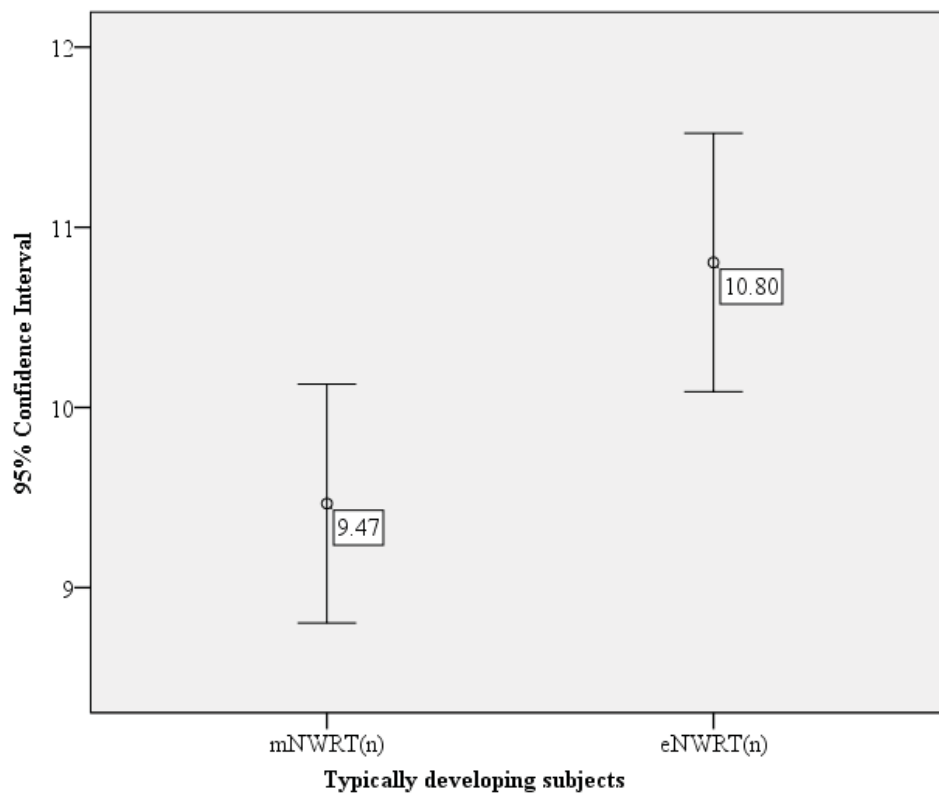


Figure 36 Graphical illustration of the mean % error scores of the Maltese and English NWRT in noise (TD subjects)

A paired samples t-test was carried out to explore whether the difference in performance between the two subtests was statistically significant. The normalised data (refer to appendix C table 24) was used for this analysis. The results demonstrated that the difference in performance between the two subtests: mNWRT(n) (M= 2.20, SD =.31) and eNWRT(n) (M= 2.33, SD=.33) was statistically significant: $t(97) = -3.247$, $p = .002$.

The same plot was constructed for the children forming the clinical group. Contrary to the TD group, these children were found to exhibit higher mean percentage errors in the Maltese subtest, as is illustrated in figure 37.

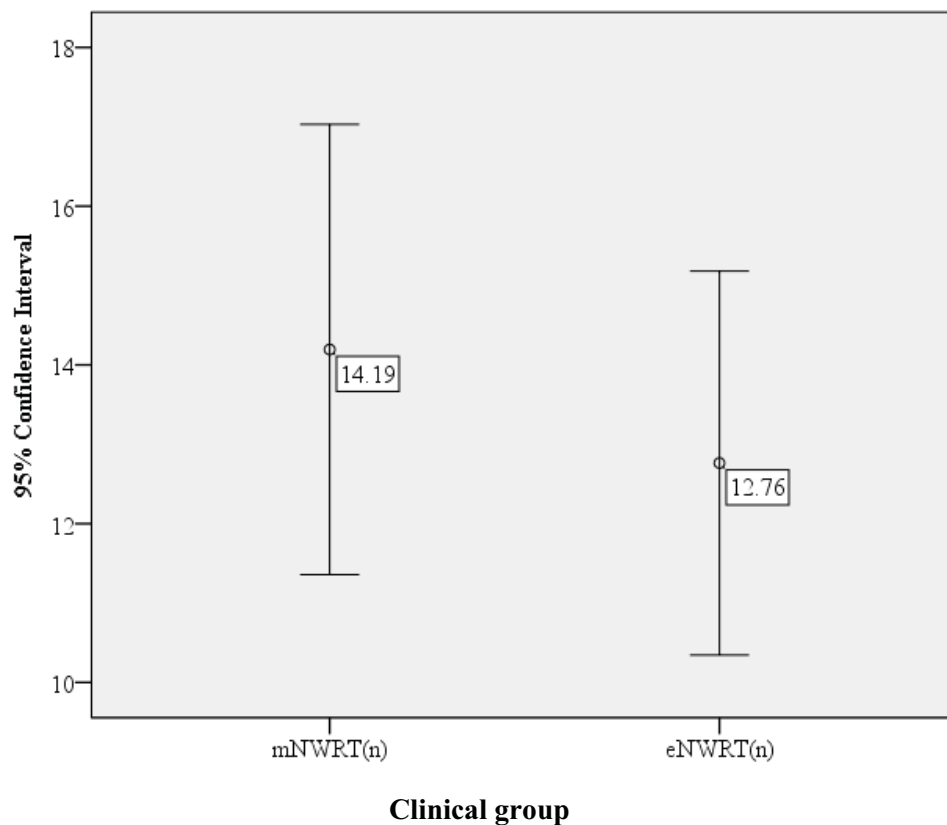


Figure 37 Graphical illustration of the mean % error scores of the Maltese and English NWRT in noise (clinical group)

The Wilcoxon signed ranks test resulted in no statistically significant difference in performance between the two subtests in this group: $z = -1.257$, $p = .209$ ³¹.

5.3.3 Sub-tests using linguistic content: Dichotic Digits (DD) tests

5.3.3.1 *The effect of age group on the Dichotic Digit tests*

Boxplot

³¹ The paired t test on the normalised data could not be carried out because the standard error of the difference was 0.

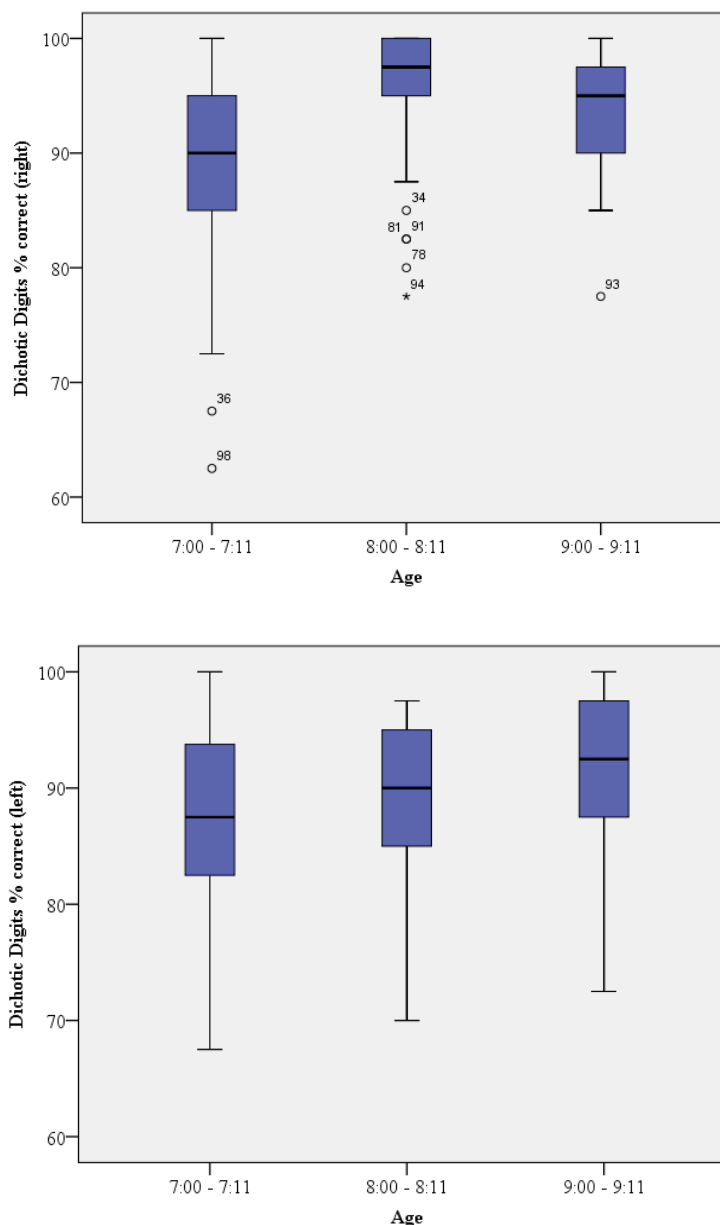


Figure 38 Graphical illustration of the median Dichotic Digits (free recall) (DDFR) % correct scores categorised by ‘age group’

The Dichotic Digits (free recall) (DDFR) percentage correct scores of the subjects across age groups are displayed in figure 38, with the supporting descriptive statistics explained in table 25 of appendix C. The mean scores ranged between 88.8 and 94.9% in the right ear (RE), and between 87.0 and 91.0% in the left ear. The 7-year-old group obtained a lower mean percentage score than the 8 and 9-year-old groups.

Boxplot

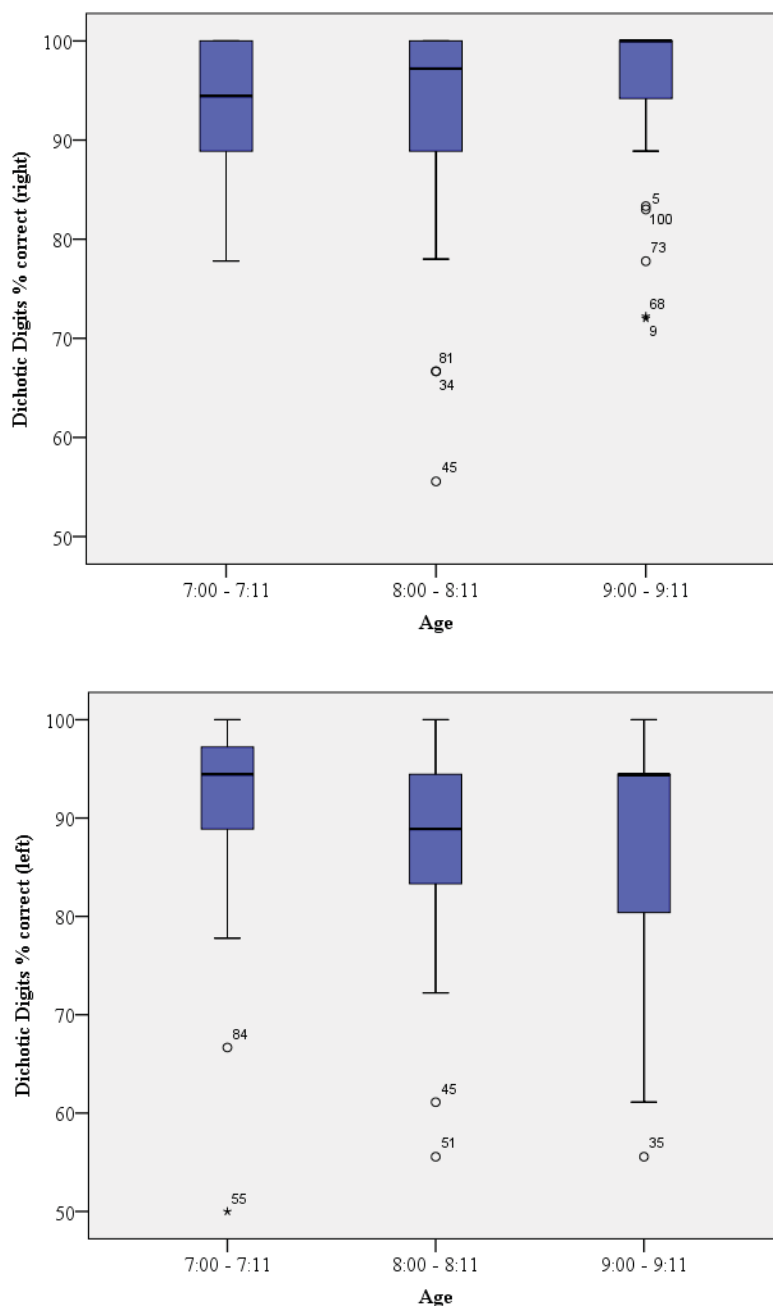


Figure 39 Graphical illustration of the median Dichotic Digits (focused attention) % correct scores categorised by ‘age group’

The percentage correct mean scores for the ‘focused attention’ (DDFA) subtest (appendix C table 26) show an overall higher mean percentage correct score obtained for the RE (between 92.0 and 94.8%) when compared with the LE (between 87.5 and 91.3%). A fair

amount of overlap is evident as shown in the boxplots of figure 39, suggesting similar performance across groups.

Both the K-S and S-W tests of normality suggested mainly data of non-normal distribution, even following normalisation of data (appendix C table 27). This was consistent with the skewness and kurtosis z scores (appendix C table 26), which were mostly outside the ± 3.29 range.

The effect of age on the DD tests was analysed through the K-W test for each ear. In the FR subtest, a statistically significant difference was found between age groups for the RE results ($H(2) = 13.833$, $p = .001$), where the 8;00-8;11 and 9;00-9;11 year old age groups obtained higher scores than the 7;00-7;11 age group. No statistically significant difference was seen in the LE results ($H(2) = 5.254$, $p = .072$). In the FA subtest no statistically significant difference emerged in both ears: RE results ($H(2) = 0.724$, $p = .696$); LE results ($H(2) = 4.068$, $p = .131$)³².

5.3.3.2 *The effect of gender on the Dichotic Digit tests*

A similar performance with marginal differences was exhibited by both males and females in the DD(FR) tests for both left and right sides. The reader is referred to figure 40 and table 28 of appendix C for further detail on their performance.

³² The parametric equivalent (one-way between subjects ANOVA) was in agreement: DD(FR) RE= [F(2,94) = 7.199, $p = .001$]; LE = [F(2,94) = 1.959, $p = .147$]. Post-Hoc comparisons using the Tukey HSD test on the RE indicated that the mean score of the '7;00 -7;11' group ($M=88.75$, $SD=8.82$) differed significantly from the '8;00 - 8;11' group ($M=94.85$, $SD=6.18$) and the '9;00 - 9;11' group ($M=93.82$, $SD=5.53$).

DD(FA) RE= [F(2,97) = 0.412, $p = .664$]; LE = [F(2,97) = 1.076, $p = .345$].

Boxplot

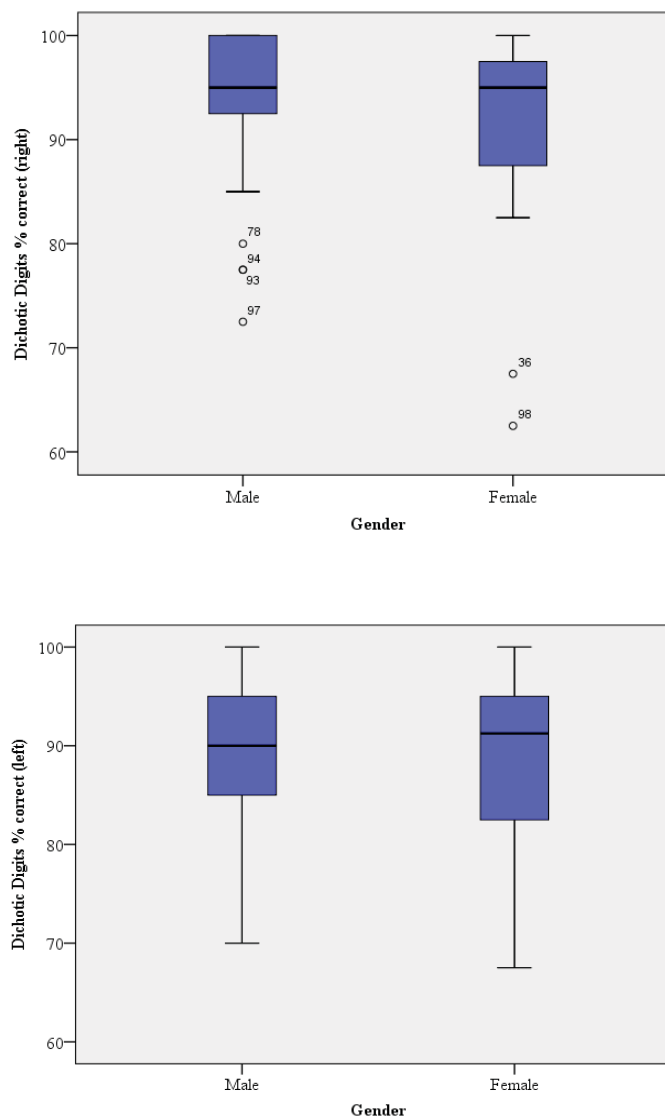


Figure 40 Graphical illustration of the median Dichotic Digits (free recall) % correct scores categorised by ‘gender’

A similar pattern was observed in the DD(FA) subtest. While it was found that the females in this sample obtained higher percentage correct scores when compared to the males, the difference was marginal (as is depicted in figure 41 and appendix C, table 29)

Boxplot

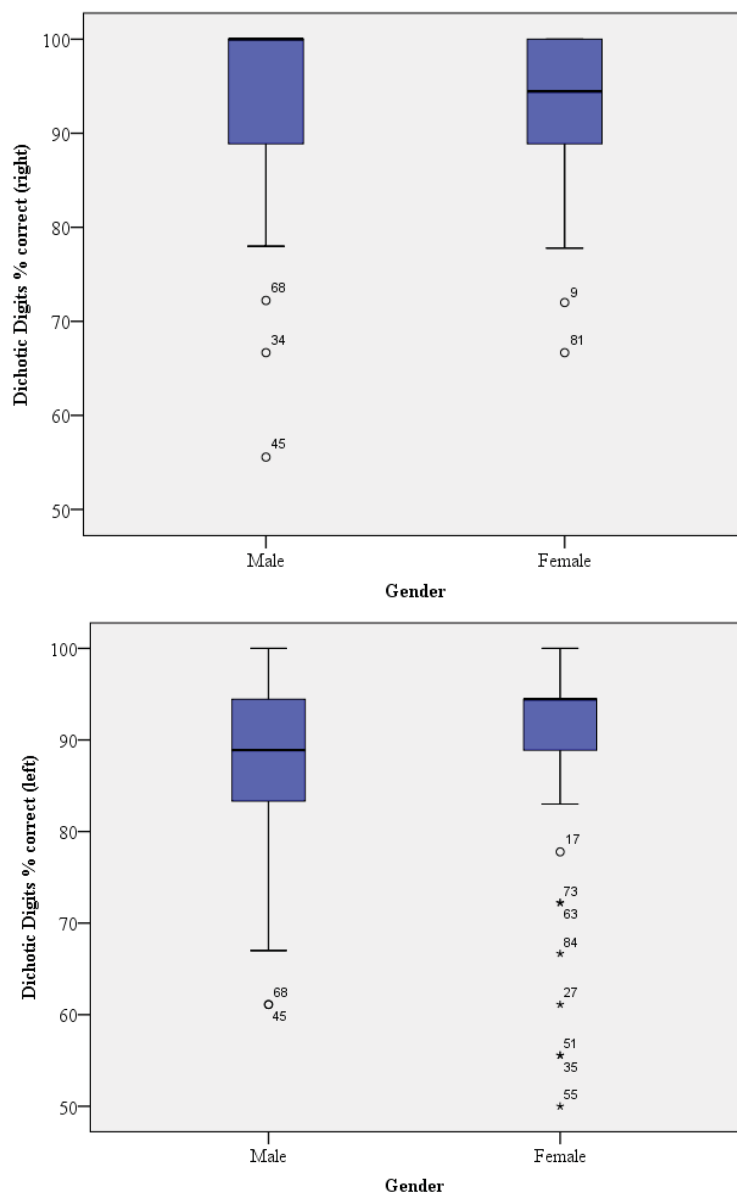


Figure 41 Graphical illustration of the median Dichotic Digits (focused attention) %

correct scores categorised by 'gender'

Both the K-S and S-W tests and the skewness/kurtosis z scores suggested predominantly data of non-normal distribution (refer to appendix C table 30 for K-S/S-W results and table 66 for skewness/kurtosis z scores). 'Ln' transformation of the data still resulted in data of non-normal distribution. The M-W test was used therefore used to review

the effect of ‘gender’ on the percentage correct scores of the two DD subtests. The result showed no statistically significant difference between the two groups in all subtests:

- DD(FR), right: $U=931.0$, $p=.108$ between the ‘male’ (Mdn=95.0) and the ‘female’ (Mdn=95.0) groups
- DD(FR), left: $U=1084.5$, $p=.641$ between the ‘male’ (Mdn=90.0) and the ‘female’ (Mdn=91.25) groups
- DD(FA), right: $U=1185.0$, $p=.853$ between the ‘male’ (Mdn=100.0) and the ‘female’ (Mdn=94.4) groups
- DD(FA), left: $U=1020.0$, $p=.177$ between the ‘male’ (Mdn=88.9) and the ‘female’ (Mdn=94.4) groups³³

5.3.3.3 *The effect of geographic region on the Dichotic Digit tests.*

The participants living in the North performed better on the DDFR than those living in the South, with the difference being greater in the left ear (refer to figure 42 and appendix C table 31). A different pattern was observed in the DDFA subtest, where the participants

³³ The parametric equivalent (independent samples t-test) was in agreement –

- DD(FR), right: ‘male’ (M= 94.72, SD =7.00) and ‘female’ (M= 91.70, SD=7.69) groups: $t(95)= 1.328$, $p=.187$.
- DD(FR), left: ‘male’ (M= 88.60, SD =7.95) and ‘female’ (M= 89.06, SD=8.32) groups: $t(95)= -.277$, $p=.782$.
- DD(FA), right: ‘male’ (M= 93.48, SD =10.24) and ‘female’ (M= 94.25, SD=7.67) groups: $t(98)= -.427$, $p=.671$.
- DD(FA), left: ‘male’ (M= 88.18, SD =10.24) and ‘female’ (M= 89.64, SD=11.65) groups: $t(98)= -.648$, $p=.519$.

from the South scored better than those from the North in the left ear, but worse in the right ear (refer to figure 43 and appendix C table 32).

Boxplot

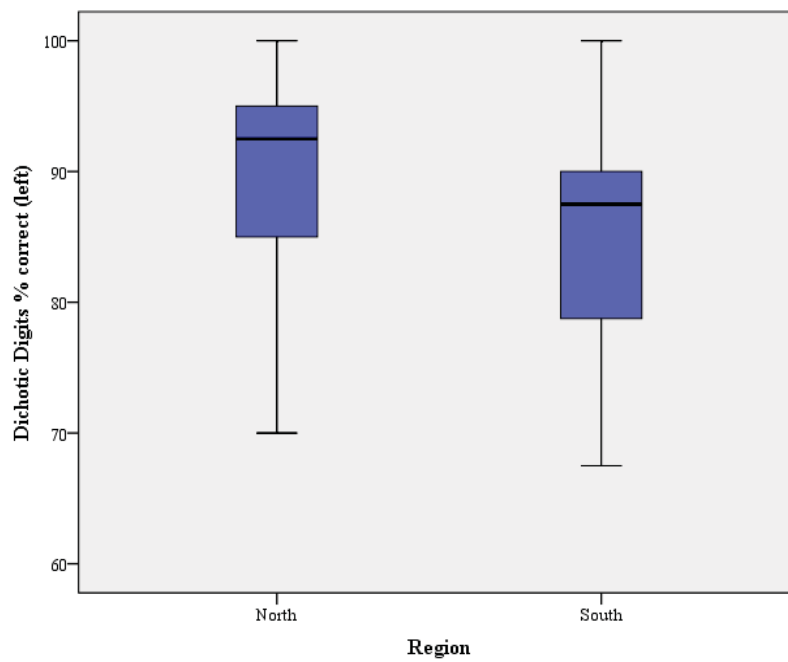
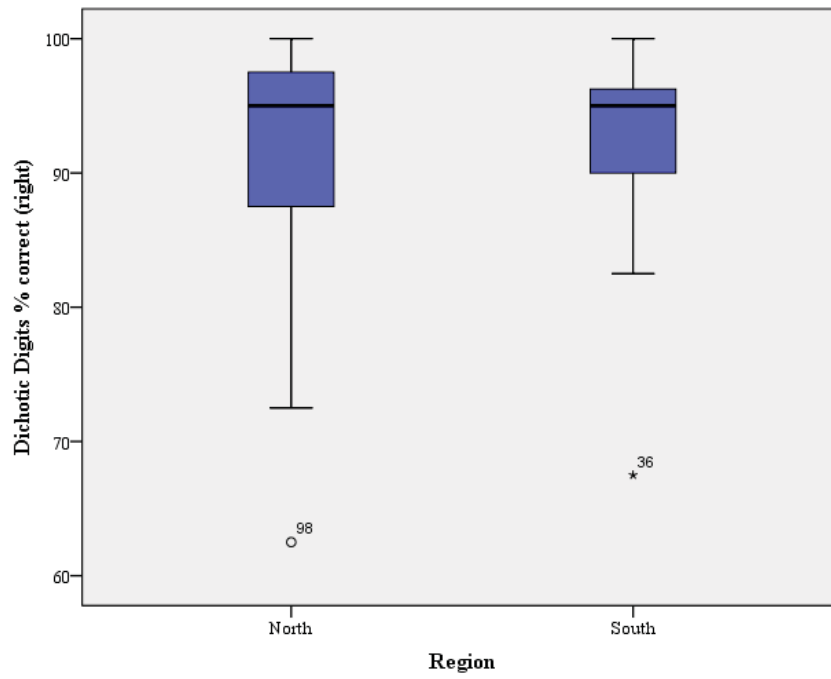


Figure 42 Graphical illustration of the median Dichotic Digits (free recall) % correct scores categorised by 'geographic region'

Boxplot

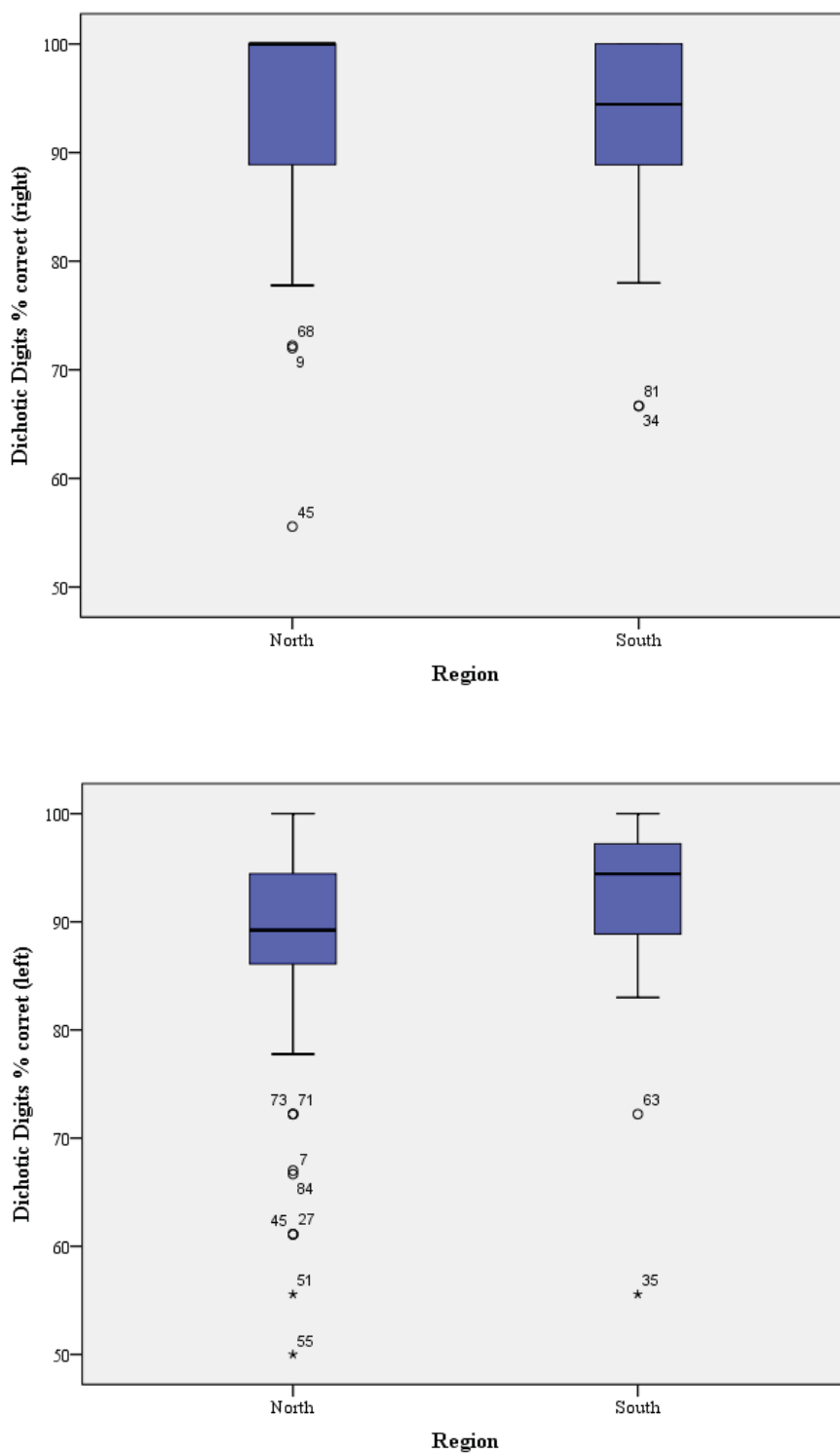


Figure 43 Graphical illustration of the median Dichotic Digits (focused attention) % correct scores categorised by 'region'

As indicated by the K-S and S-W tests of normality (appendix C table 33), as well as well as the skewness and kurtosis z score values the data are predominantly of non-normal

distribution. Non-parametric testing evaluated the effect of ‘region’ on the percentage correct scores of the two DD subtests is explained next:

- DDFR, right: $U=770.5$, $p=.489$ between the ‘North’ (Mdn=95.0) and the ‘South’ (Mdn=95.0) groups
- DDFR, left: $U=557.5$, $p=.012$ between the ‘North’ (Mdn=92.5) and the ‘South’ (Mdn=87.5) groups
- DDFA, right: $U=689.0$, $p=.052$ between the ‘North’ (Mdn=100.0) and the ‘South’ (Mdn=94.4) groups
- DDFA, left: $U=833.5$, $p=.520$ between the ‘North’ (Mdn=89.24) and the ‘South’ (Mdn=94.42) groups³⁴

The result showed a statistically significant difference between the two groups in the DDFR for the left ear. A possible trend towards significance also emerged in the DDFA for the right ear. In both cases it emerged that the participants living in the North of the island performed better than the participants living in the South.

5.3.3.4 *The effect of school type on the Dichotic Digit tests.*

When the participants were divided in terms of the school type attended, it emerged that although the performance on the DDFR was similar between schools in both ears (as

³⁴ The parametric equivalent (independent samples t-test) was in agreement –

- DD(FR), right: ‘North’ (M= 92.7, SD =7.50) and ‘South’ (M= 92.0, SD=7.33) groups: $t(95)= .357$, $p=.722$.
- DD(FR), left: ‘North’ (M= 90.03, SD =7.68) and ‘South’ (M= 85.11, SD=8.54) groups: $t(95)= 2.615$, $p=.010$.
- DD(FA), right: ‘North’ (M= 94.65, SD=8.4) and ‘South’ (M= 91.66, SD=9.69) groups: $t(98)= 1.465$, $p=.146$.
- DD(FA), left: ‘North’ (M= 88.52, SD =11.34) and ‘South’ (M= 90.71, SD=10.19) groups: $t(98)= -.844$, $p=.401$.

demonstrated in the box plots of figure 44), the children attending the independent schools achieved the highest scores (see figure 44) and appendix C table 34).

Boxplot

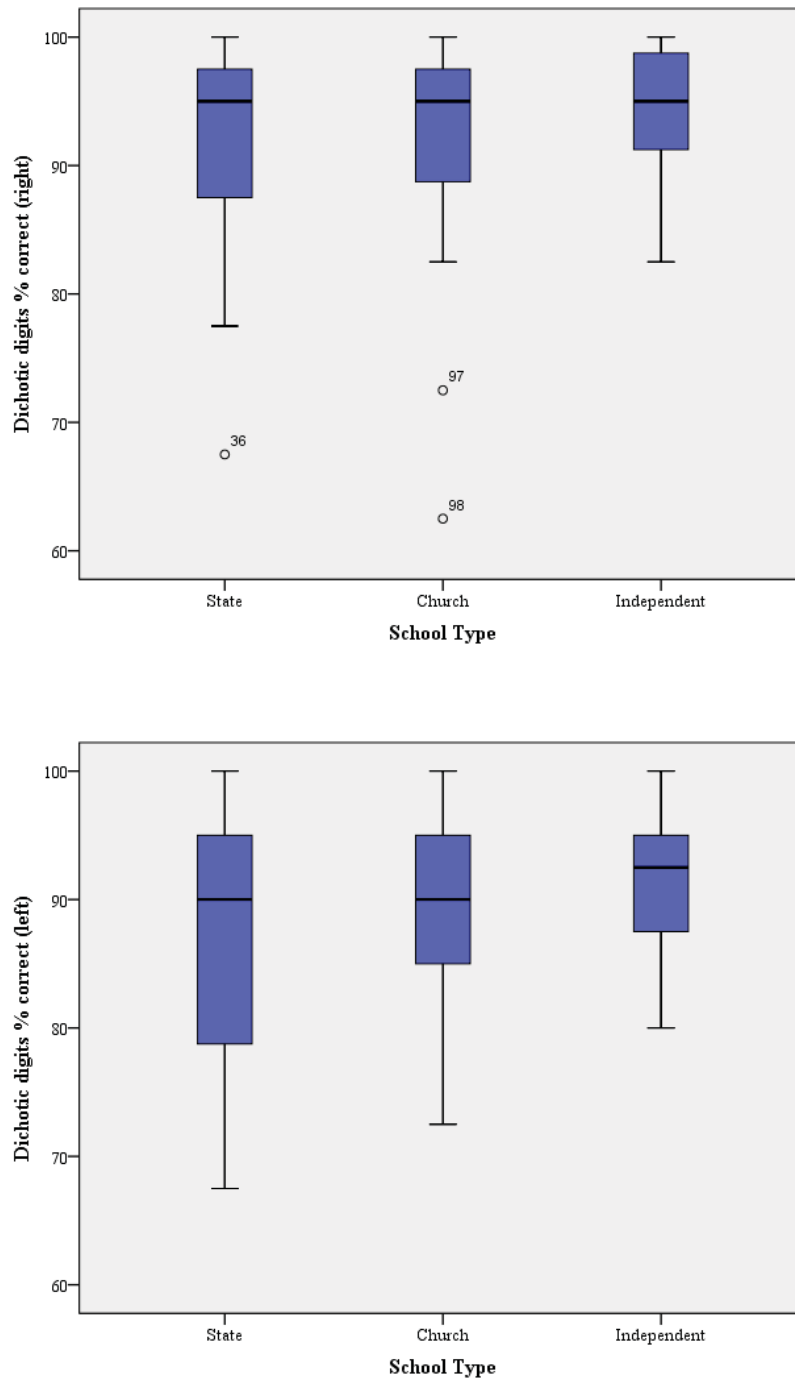


Figure 44 Graphical illustration of the median Dichotic Digits (free recall) % correct scores categorised by 'school type'

Similar performance between groups was also observed in the DDFA subtest (refer to box plots of figure 45). However, while the participants attending independent schools obtained the highest score in the right ear, this same group obtained the lowest score in the left ear.

Boxplot

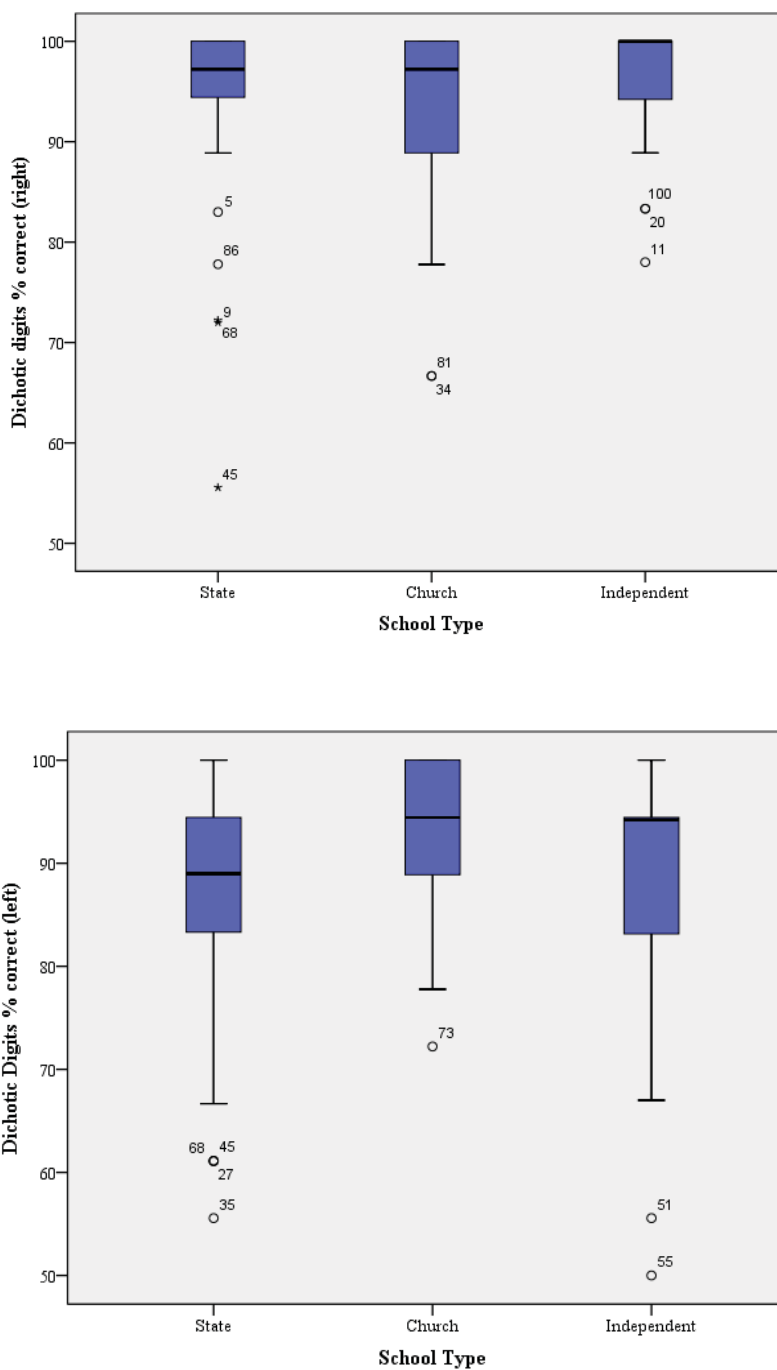


Figure 45 Graphical illustration of the median Dichotic Digits (focused attention) % correct scores categorised by 'school type'

The tests of normality (appendix C table 36) as well as the skewness and kurtosis values (appendix C tables 34 and 35) indicate mainly data of non-normal distribution. Non

parametric tests were used to investigate whether the difference in performance between the groups was statistically significant. In both subtests no statistically significant difference was found between school types for both ears: (1) DDFR right ear ($H(2) = 0.590, p=.744$); (2) DDFR left ear ($H(2) = 3.617, p=.164$); (3) DDFA right ear ($H(2) = 0.635, p=.728$); (4) DDFA left ear ($H(2) = 2.758, p=.252$)³⁵.

5.3.3.5 *The effect of primary language on the Dichotic Digit tests*

The participants were divided in terms of their PL. The children whose PL is Maltese obtained an overall lower mean score in the DDFR than the children who used English as a PL in both ears (see figure 46 and the mean scores of appendix C table 37). More variability in performance was also observed in the former group as is demonstrated in the box plots of figure 46.

Boxplot

³⁵ The parametric equivalent (one-way between subjects ANOVA) was in agreement: DD(FR) RE= [F(2,94) = 0.773, p = .465]; LE = [F(2,94) = 2.866, p = .062]; DD(FA) RE= [F(2,97) = .498, p = .609]; LE = [F(2,97) = 2.533, p = .085]

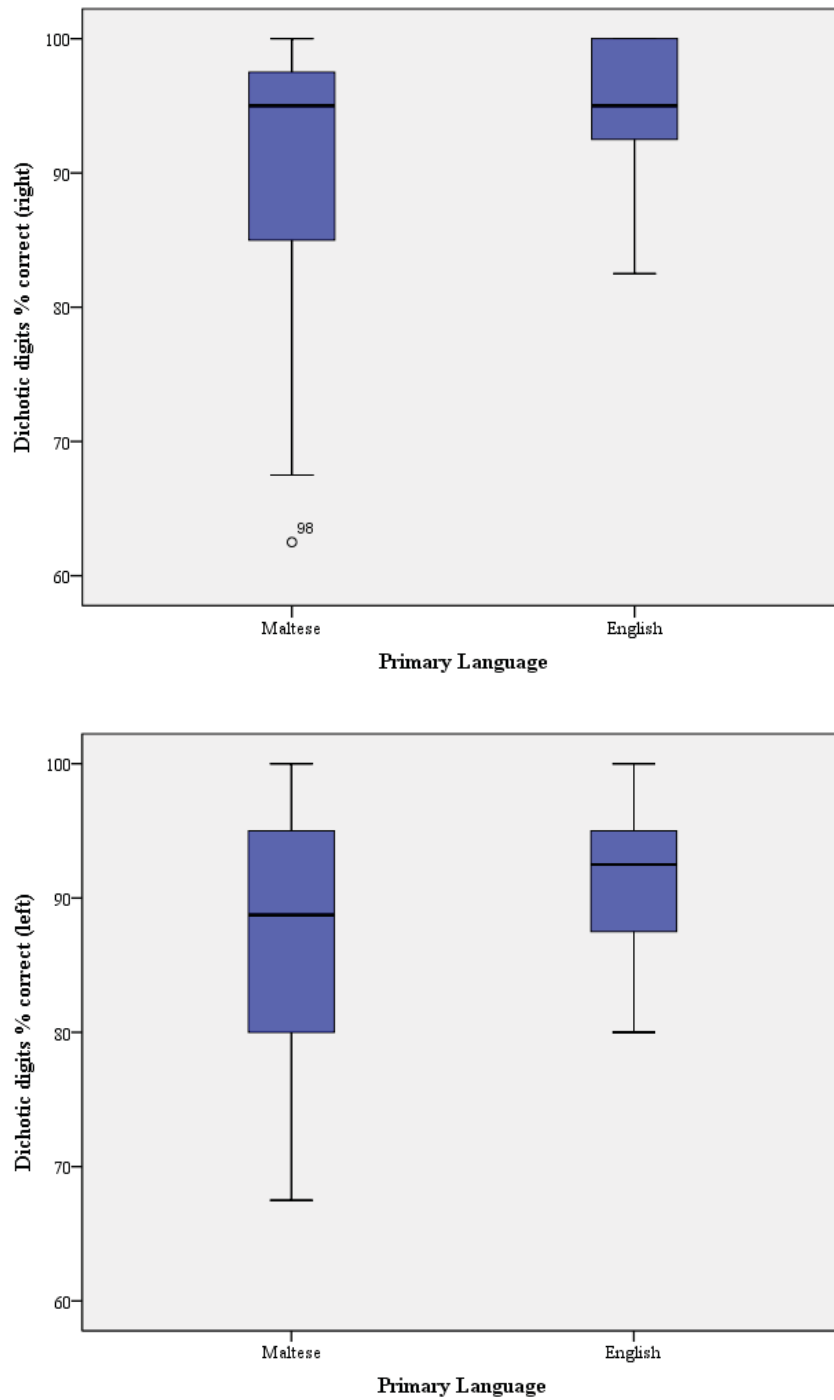


Figure 46 Graphical illustration of the median Dichotic Digits (free recall) % correct scores categorised by 'primary language'

In the DDFA subtest the participants who used English as a PL obtained a higher score in the right ear than those who used Maltese. A similar score was obtained on the left side by both groups (see figure 47 and the mean scores in appendix C table 38). In contrast with the DDFR, there was less variability in scores achieved by the PL Maltese participants (see box plots of figure 47).

Boxplot

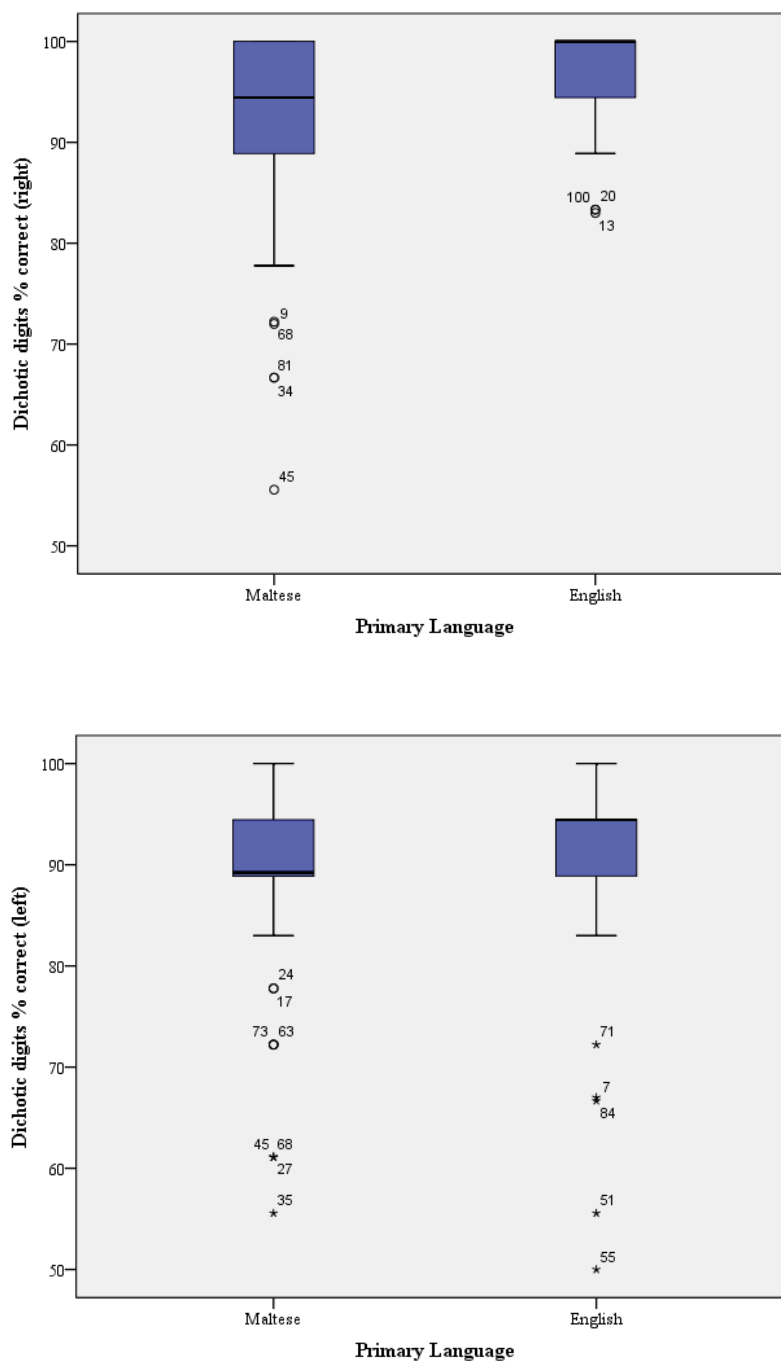


Figure 47 Graphical illustration of the median Dichotic Digits (focused attention) % correct scores categorised by 'primary language'

The K-S and S-W test of normality indicate data of non-normal distribution, even following the Ln transformation technique (appendix C table 39). The Mann-Whitney test

was used to evaluate the effect of ‘primary language’ on the percentage correct scores of the two DD subtests as shown next:

- DDFR, right: $U=853.5$, $p=.029$ between the ‘Maltese’ (Mdn=95.0) and the ‘English’ (Mdn=95.0) groups
- DDFR, left: $U=820.5$, $p=.016$ between the ‘Maltese’ (Mdn=86.8) and the ‘English’ (Mdn=92.5) groups
- DDFA, right: $U=948.5$, $p=.042$ between the ‘Maltese’ (Mdn=94.4) and the ‘English’ (Mdn=100) groups
- DDFA, left: $U=1165$, $p=.707$ between the ‘Maltese’ (Mdn=89.24) and the ‘English’ (Mdn=94.4) groups³⁶

5.3.3.6 *The effect of pathology on the Dichotic Digit tests*

The performance of the TD group on the DD tests was compared with the clinical group. The clinical group scored lower than the TD group in all subtests for both ears, as is evident through the mean scores in tables 40 and 41 of appendix C. The boxplots in figures

³⁶ The parametric equivalent (independent samples t-test) was in agreement –

- DD(FR), right: ‘Maltese’ (M= 90.9, SD =8.47) and ‘English’ (M= 94.8, SD=5.06) groups: $t(91.7)=-2.767$, $p=.007$.
- DD(FR), left: ‘Maltese’ (M= 86.8, SD =9.15) and ‘English’ (M= 91.7, SD=5.44) groups: $t(91.6)=-3.235$, $p=.002$.
- DD(FA), right: ‘Maltese’ (M= 92.1, SD=10.31) and ‘English’ (M= 96.4, SD=5.21) groups: $t(88.9)=-2.713$, $p=.008$.
- DD(FA), left: ‘Maltese’ (M= 89.1, SD =10.86) and ‘English’ (M= 89.02, SD=11.47) groups: $t(98)=-.019$, $p=.985$.

48 and 49 also show greater variability in the scores obtained by the clinical group. This was especially evident in the 'focused attention' subtest.

Boxplot

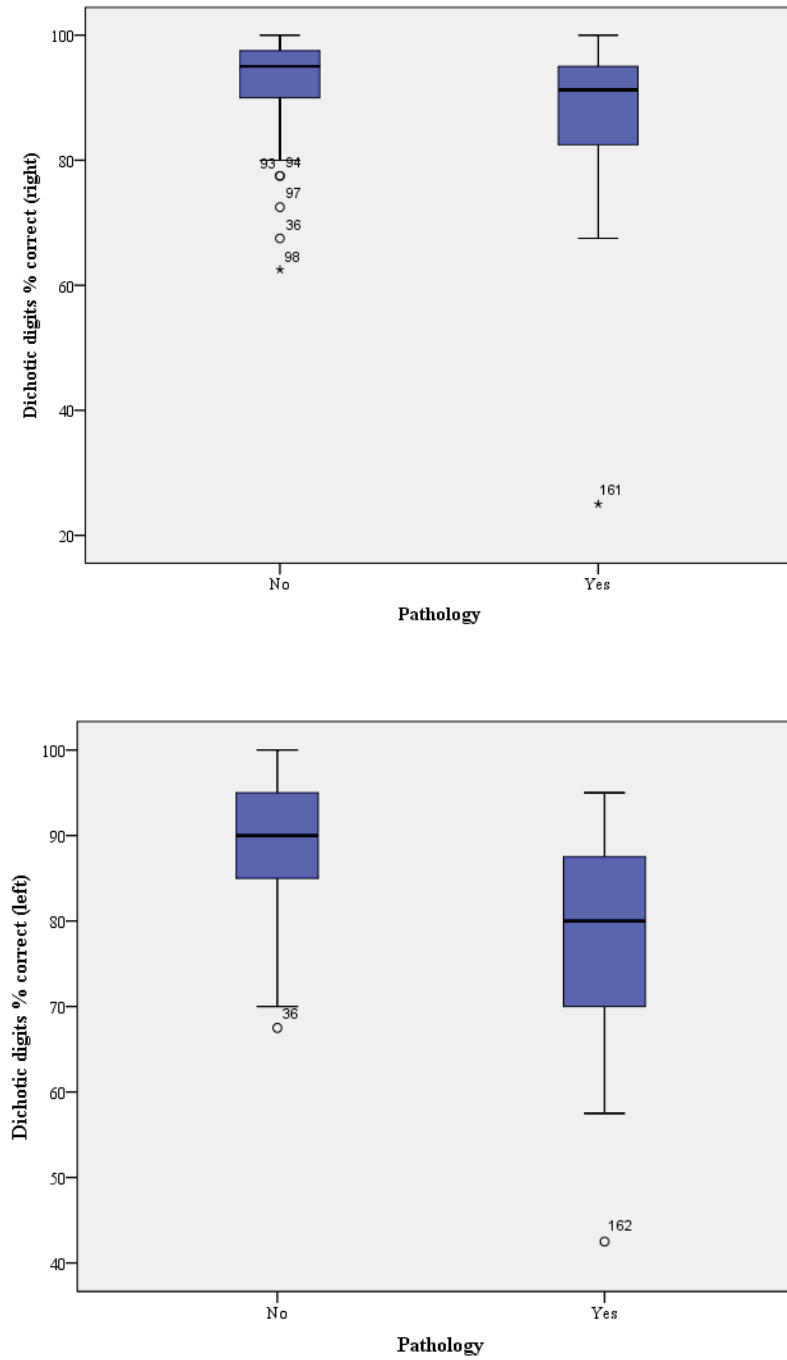


Figure 48 Graphical illustration of the median Dichotic Digits (free recall) % correct scores categorised by ‘pathology’

Boxplot

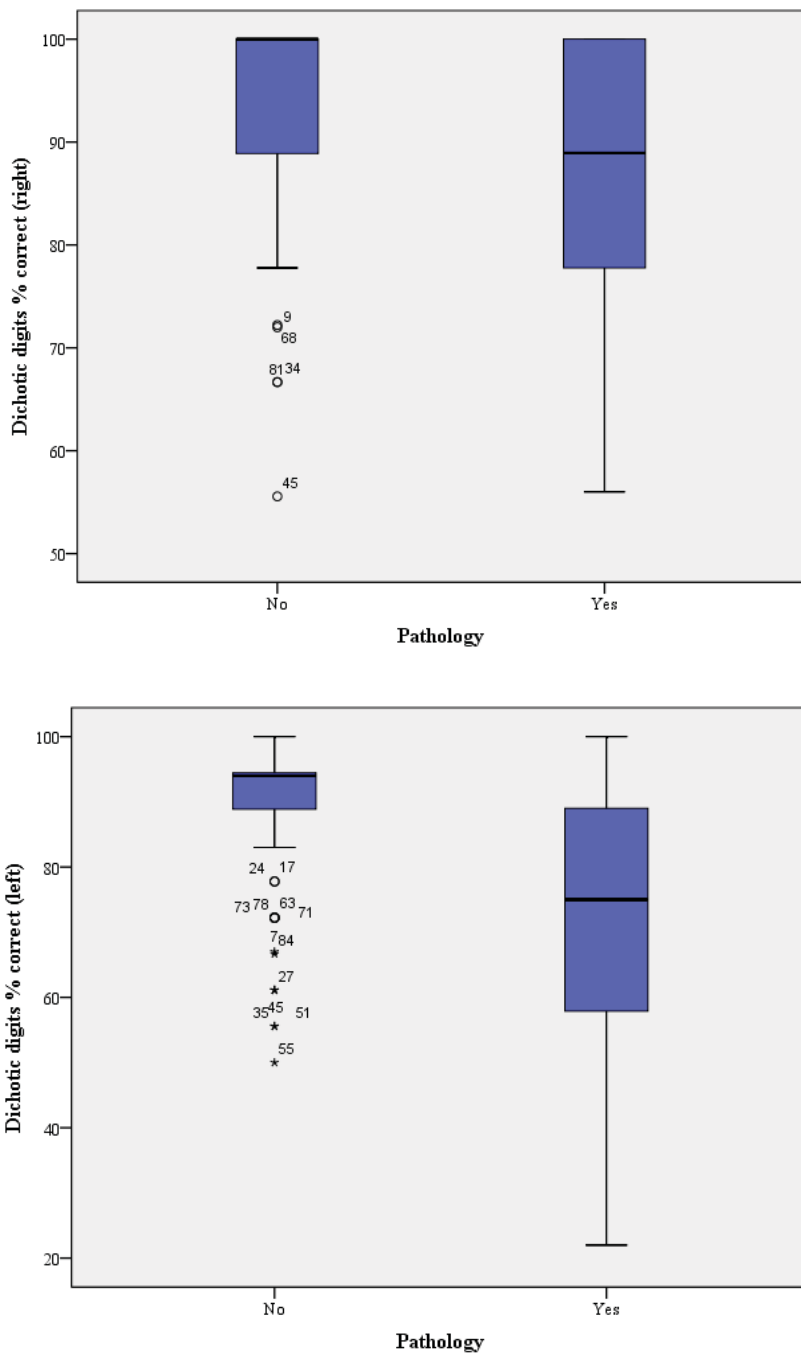


Figure 49 Graphical illustration of the median Dichotic Digits (focused attention) % correct scores categorised by ‘pathology’

The skewness/kurtosis values (appendix C tables 40 and 41) as well as the tests of normality (appendix C table 42) indicate mainly data of non-normal distribution. The Mann-

Whitney was applied to examine whether the difference in performance between the two groups was statistically significant; results of which follow:

- DDFR, right: $U=956.5$, $p=.056$ between the ‘typically developing’ ($Mdn=95.0$) and the ‘pathology’ ($Mdn=95.0$) groups
- DDFR, left: $U=622.0$, $p < .001$ between the ‘typically developing’ ($Mdn=95.0$) and the ‘pathology’ ($Mdn=95.0$) groups
- DDFA, right: $U=1013$, $p=.005$ between the ‘typically developing’ ($Mdn=95.0$) and the ‘pathology’ ($Mdn=95.0$) groups
- DDFA, left: $U=710.5$, $p < .001$ between the ‘typically developing’ ($Mdn=95.0$) and the ‘pathology’ ($Mdn=95.0$) groups³⁷

A statistically significant difference was found between the performance of the two groups in both ears of the DDFA and in the left ear of the DDFR. The difference between the scores obtained from the right ear of the DDFR approached but did not quite achieve significance.

5.4.3.7 *Analysis of ear effects*

The previous sections have highlighted some statistically significant differences in the percentage correct scores when categorised into some of the independent variables as summarised below:

³⁷ The parametric equivalent (independent samples t-test) was in agreement –

- DD(FR), right: ‘typically developing’ ($M= 92.6$, $SD =7.44$) and ‘pathology’ ($M= 87.1$, $SD=15.42$) groups: $t(28)= 1.757$, $p=.090$.
- DD(FR), left: ‘typically developing’ ($M= 88.9$, $SD =8.13$) and ‘pathology’ ($M= 78.1$, $SD=13.5$) groups: $t(30)= 3.892$, $p=.001$.
- DD(FA), right: ‘typically developing’ ($M= 93.9$, $SD =8.77$) and ‘pathology’ ($M= 86.9$, $SD=13.21$) groups: $t(37)= 2.754$, $p=.009$.
- DD(FA), left: ‘typically developing’ ($M= 89.0$, $SD =11.06$) and ‘pathology’ ($M= 71.8$, $SD=20.9$) groups: $t(34)= 4.351$, $p <.001$.

- DDFR
 - Age group
 - Geographic region
 - Primary language
 - Pathology
- DDFA
 - Primary language
 - Pathology

This section will compare and contrast the percentage correct scores obtained in the right and left ears in terms of these categories.

Ear effects of the DDFR in terms of 'age group' (TD participants only). Figure 50 displays bar graphs of the right and left ear score for each age group.

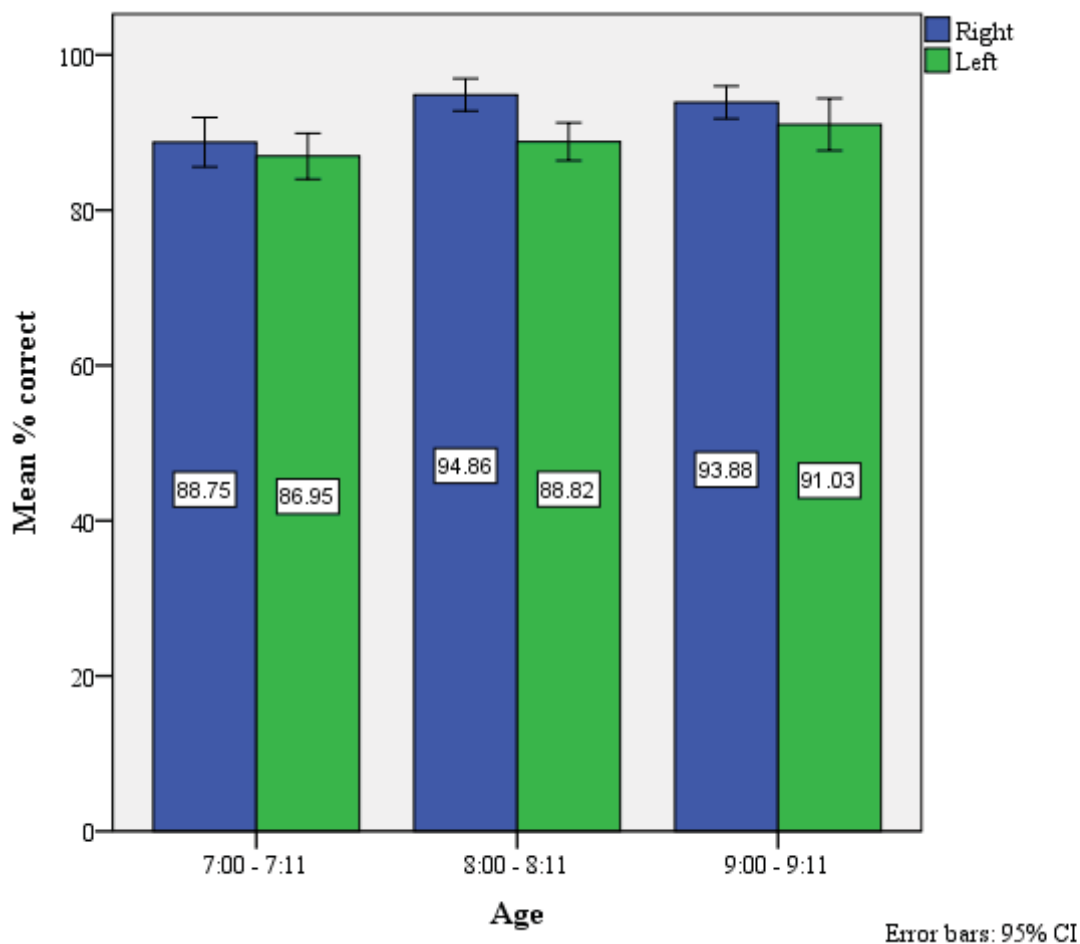


Figure 50 DDFR right and left ear percentage correct scores categorised by 'age group'

A comparison of the right and left ear scores revealed no statistically significant difference in the 7:00 – 7:11 age group for the right (Mdn=90.0) and left (Mdn=87.5) ears, $Z = -1.40$, $p = .162$, as well as in the 9:00 – 9:11 age group (right Mdn = 95.0; left Mdn = 92.5), $Z = -1.612$, $p = .093$. A statistically significant difference emerged in the 8:00 – 8:11 age group, where the right ear score (Mdn = 97.5) was significantly higher than the left ear score (Mdn = 90.0), $Z = -3.602$, $p < .001$ ³⁸.

³⁸ The parametric equivalent was in agreement: DDFR in the

- 7:00 – 7:11 year old group showed no statistically significant difference between the right (M=88.75, SD=8.82) and left (M=86.95, SD=8.20) ears, $t(31) = 1.164$, $p = .253$.
- 8:00 – 8:11 year old group displayed a statistically significant difference between the right (M=94.86, SD=6.18) and the left (M=88.82, SD=7.19) ears, $t(35) = 4.049$, $p < .001$
- 9:00 – 9:11 year old group showed no statistically significant difference between the right (M=93.88, SD=5.53) and the left (M=91.03, SD=8.85) ears, $t(28) = 1.740$, $p = .093$

Ear effects of the DDFR in terms of 'geographic region' (TD participants only). The bar graph illustrated in figure 51 shows a discrepancy between the right and left ear percentage score from the participants coming from the 'South' region. This discrepancy was not so evident in the participants living in the 'North' of the island.

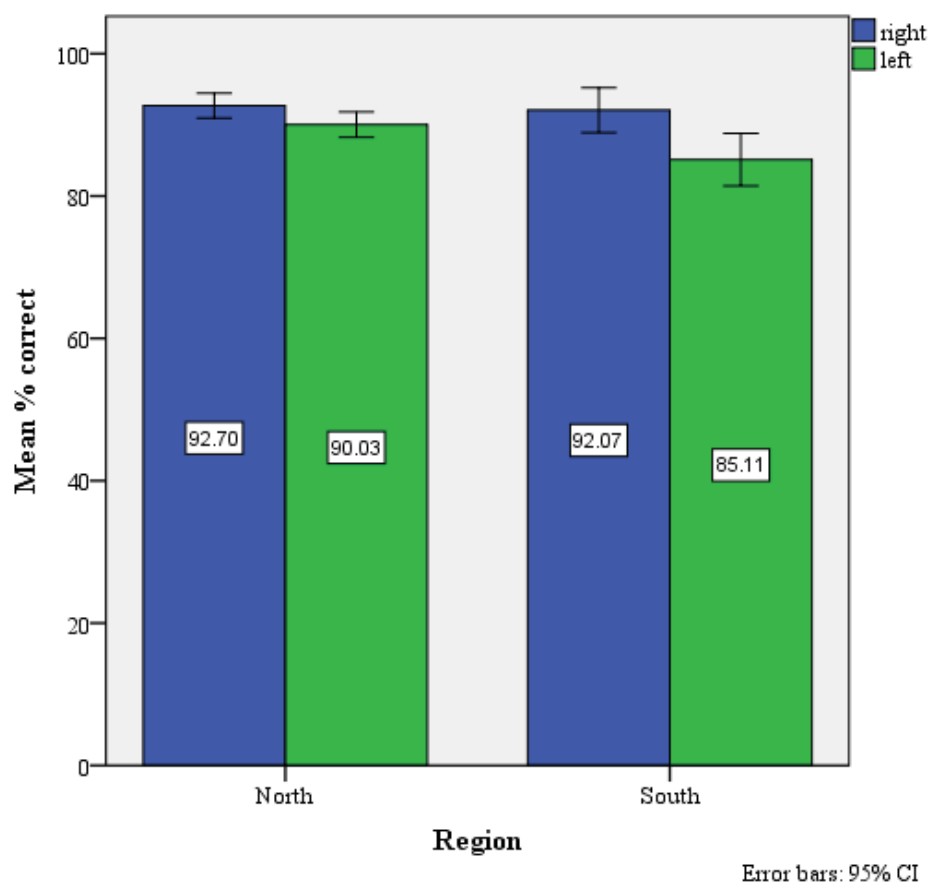


Figure 51 DDFR right and left ear percentage correct scores categorised by 'geographic region'

When the median scores for each ear were compared it emerged that the difference between the right and left was statistically significant in both the 'North' and 'South' groups as indicated below:

- 'North' group: (Right Mdn = 95, left Mdn = 92.5; $Z = -2.784$, $p = .005$)

- ‘South’ group: (Right Mdn = 95, left Mdn = 87.5; $Z = -3.208$, $p = .001$ ³⁹).

Ear effects of the DDFR in terms of ‘primary language’ (TD participants only).

Figure 52 depicts a higher percentage correct in the right ear when compared with the left in both PL groups.

³⁹ The parametric equivalent was in agreement:

- ‘North’ group (Right: $M=92.5$, $SD=7.51$, left: $M=90.03$, $SD=7.68$, $t(73) = 2.545$, $p = .013$
- ‘South’ group (Right: $M=92.07$, $SD=7.33$, left: $M=85.11$, $SD=8.54$, $t(22) = 4.164$, $p < .001$

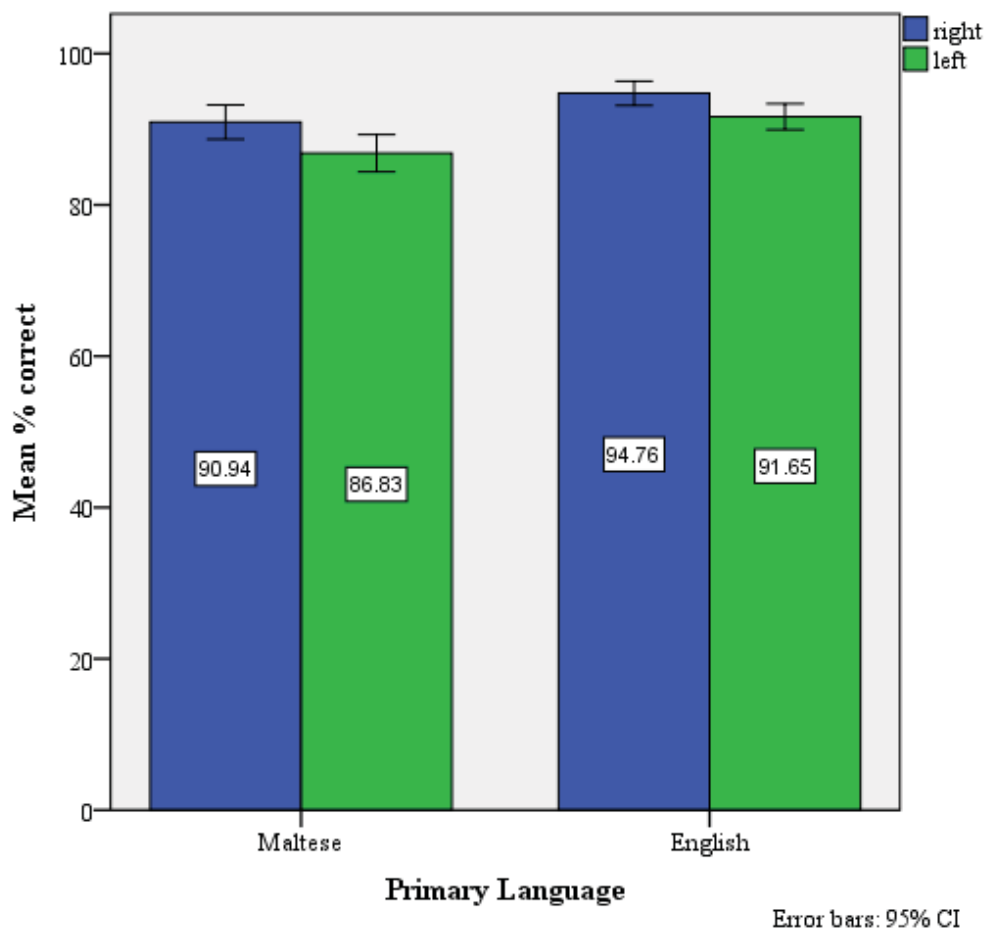


Figure 52 DDFR right and left ear percentage correct scores categorised by ‘primary language’

The difference in the score between the right and left ears was found to be statistically significant for both groups:

- ‘PL Maltese’ group: (Right Mdn = 95, left Mdn = 88.75; $Z = -2.798, p = .005$
- ‘PL English’ group: (Right Mdn = 95, left Mdn = 92.5; $Z = -3.144, p = .002$ ⁴⁰.
Ear effects of the DDFR in terms of ‘pathology’ (both TD participants and the clinical

group). In this section the comparison between ears of all the participants in the TD group is compared with the clinical group. For both groups, the bar graph as shown in figure 53,

⁴⁰ The parametric equivalent was in agreement:

- ‘PL Maltese’ group (Right: $M=90.94, SD=8.47$, left: $M=86.83, SD=9.15, t(55) = 2.879, p = .006$
- ‘PL English’ group (Right: $M=94.76, SD=5.06$, left: $M=91.65, SD=5.44, t(40) = 3.384, p = .002$

demonstrates better scores in the right ear when compared with the left, with greater variability of data in the clinical group.

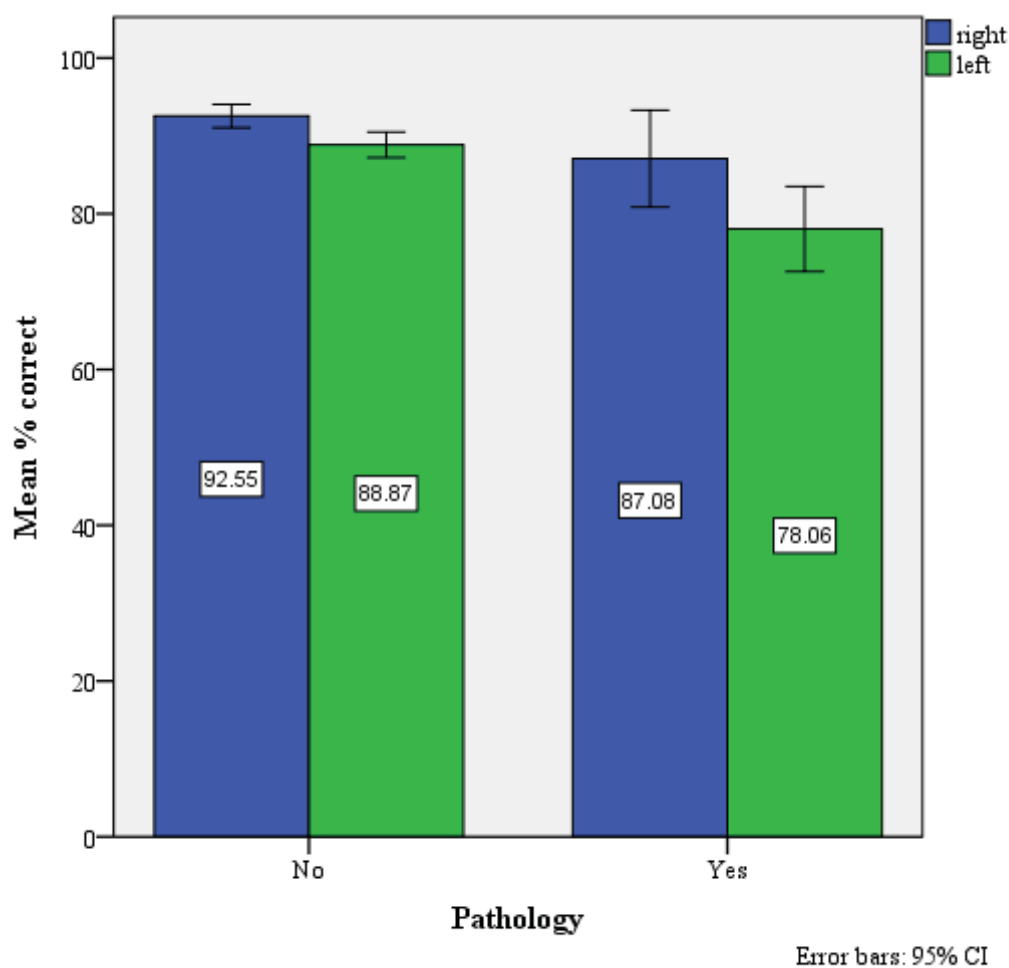


Figure 53 DDFR right and left ear percentage correct scores categorised by 'pathology'

In both groups, a statistically significant difference between the right and left ear score emerged:

- TD group: (Right Mdn = 95, left Mdn = 90; $Z = -4.038$, $p < .001$)

- clinical group: (Right Mdn = 91.25, left Mdn = 80; $Z = -2.860, p < .001$ ⁴¹).

Ear effects of the DDFA in terms of 'primary language' (TD participants only). Similarly to the DDFR, the participants were found to obtain a higher percentage correct score in their right ear on the DDFA subtest. This difference, as illustrated in figure 54, is more pronounced in the PL English group. In fact, the error bars are noted to overlap in the PL Maltese group. Using the Wilcoxon signed ranks test to analyse the PL separately, the right ear percentage correct score was found to be significantly better than the left ear score in both PL groups of this subtest:

- 'PL Maltese' group: (Right Mdn = 94.44, left Mdn = 89.24; $Z = -2.225, p = .026$
- 'PL English' group: (Right Mdn = 100, left Mdn = 94.44; $Z = -3.649, p < .001$ ⁴²

⁴¹ The parametric equivalent was in agreement:

- 'no pathology' group (Right: $M=92.55, SD=7.44$, left: $M=88.87, SD=8.13, t(96) = 4.059, p < .001$
- 'yes pathology' group (Right: $M=87.08, SD=15.42$, left: $M=78.06, SD=13.52, t(25) = 2.095, p = .046$

⁴² The parametric equivalent was in agreement for the PL English group but not for the PL Maltese group:

- 'PL Maltese' group (Right: $M=92.94, SD=10.31$, left: $M=89.06, SD=10.86, t(57) = 1.786, p = .079$
- 'PL English' group (Right: $M=96.41, SD=5.21$, left: $M=89.02, SD=11.47, t(41) = 3.806, p < .001$

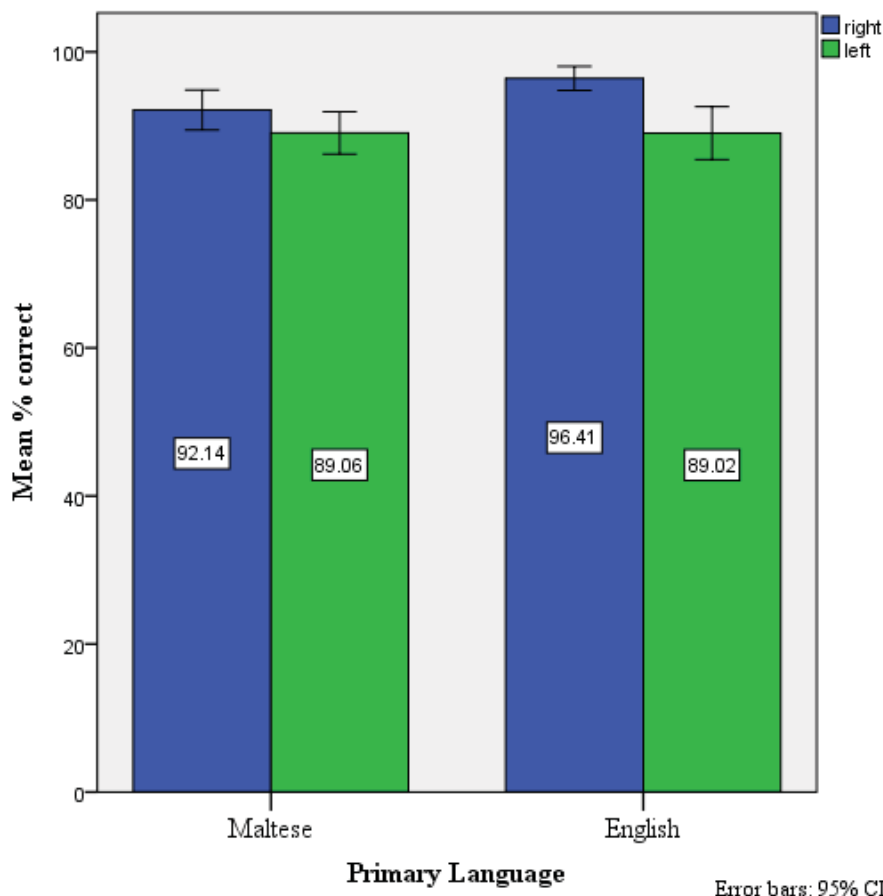


Figure 54 DDFA right and left ear percentage correct scores categorised by ‘primary language’

Ear effects of the DDFA in terms of ‘pathology’ (both TD participants and the clinical group). Figure 55 illustrates the mean percentage correct for the right and left ears in the TD and clinical groups separately. Both groups obtained a lower percentage correct score in the left hear, but this difference was found to be more pronounced in the clinical group. The ear difference was found to be statistically significant in both groups:

- TD group: (Right Mdn = 100, left Mdn = 94.0; $Z = -4.024, p < .001$)
- clinical group: (Right Mdn = 88.95, left Mdn = 75.0; $Z = -3.463, p = .001$)⁴³

⁴³ The parametric equivalent was in agreement:

- TD group (Right: $M=93.93, SD=8.77$, left: $M=89.04, SD=11.061, t(99) = 3.757, p < .001$)

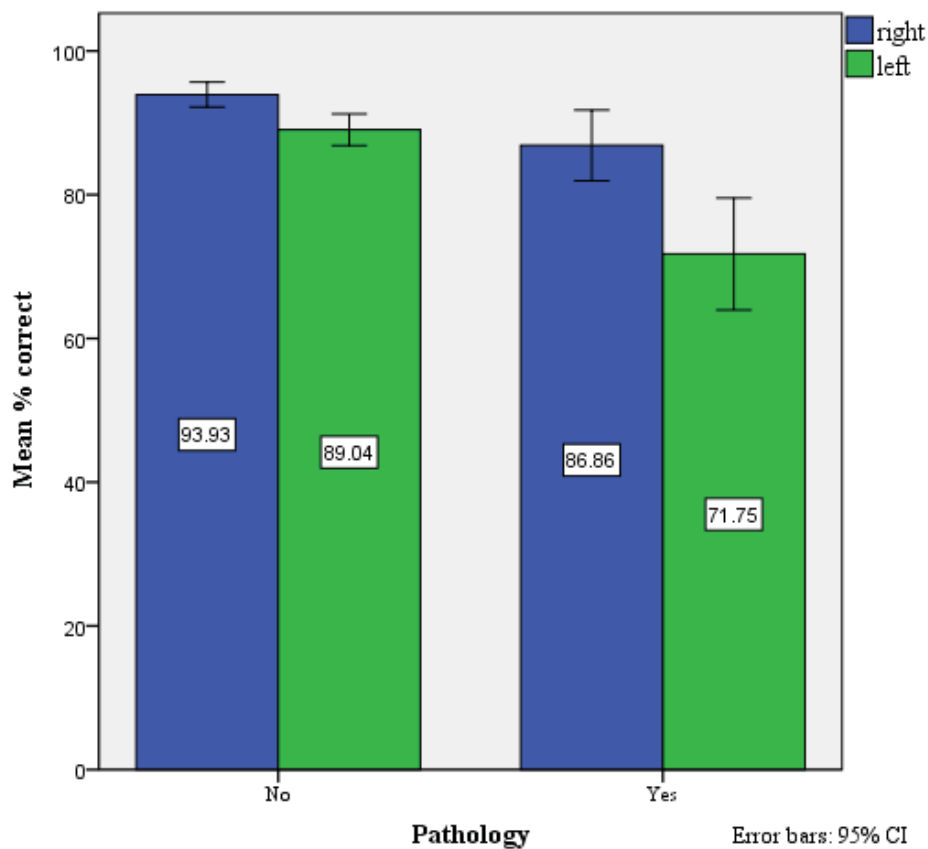


Figure 55 DDFA right and left ear percentage correct scores categorised by ‘pathology’

5.3.4 Sub-tests using non-linguistic content: Duration and Frequency Patterns

Tests

5.3.4.1 The effect of age group on the Duration and Frequency Patterns Tests. The DPT and FPT scores were categorised in terms of the age category (7;00-7;11, 8;00-8;11, and

-
- clinical group (Right: $M=86.86$, $SD=1.209$, left: $M=71.85$, $SD=20.903$, $t(29) = 4.001$, $p < .001$)

9;00-9;11 years) in which the participants fell under. In the DPT, the 7-year-old group were found to score lower than the older age groups in both ears. This is illustrated in figure 56 (also refer to mean scores in appendix C table 43). The box plots show that despite this difference in the median score, there is an amount of variation in the scores obtained by the participants of each group.

Boxplot

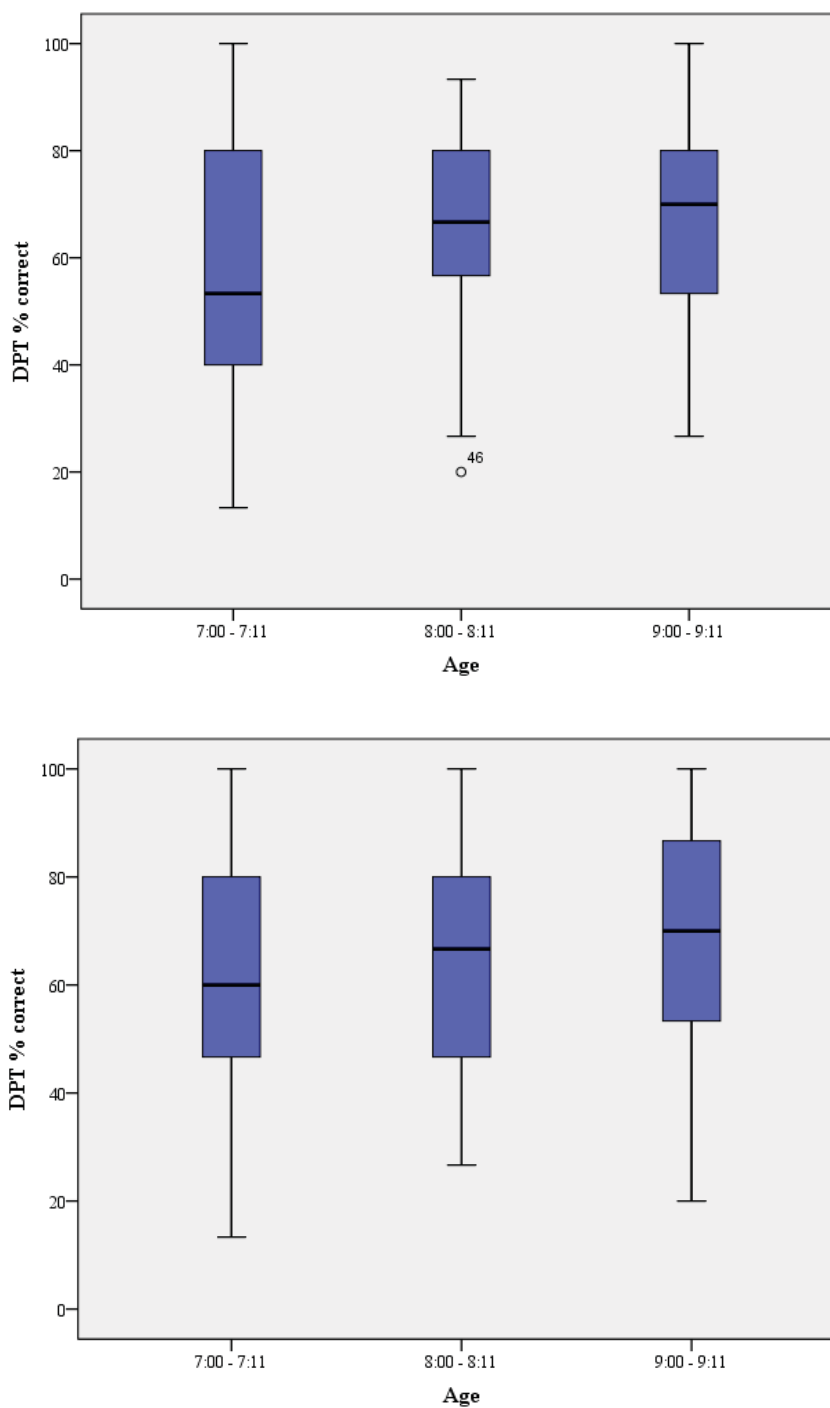


Figure 56 Graphical illustration of the median DPT % correct scores categorised by 'age group'

A similar pattern to the DPT emerged in the FTP for the right ear, where the youngest age group scored the poorest, with scores improving with increasing age. This pattern did not

emerge for the left ear. While it was still evident that the youngest age group scored lowest, the 8-year-old group obtained the highest score (figure 57). Similarly to the DPT, the box plots indicate variation in the participants' scores in each age group.

Boxplot

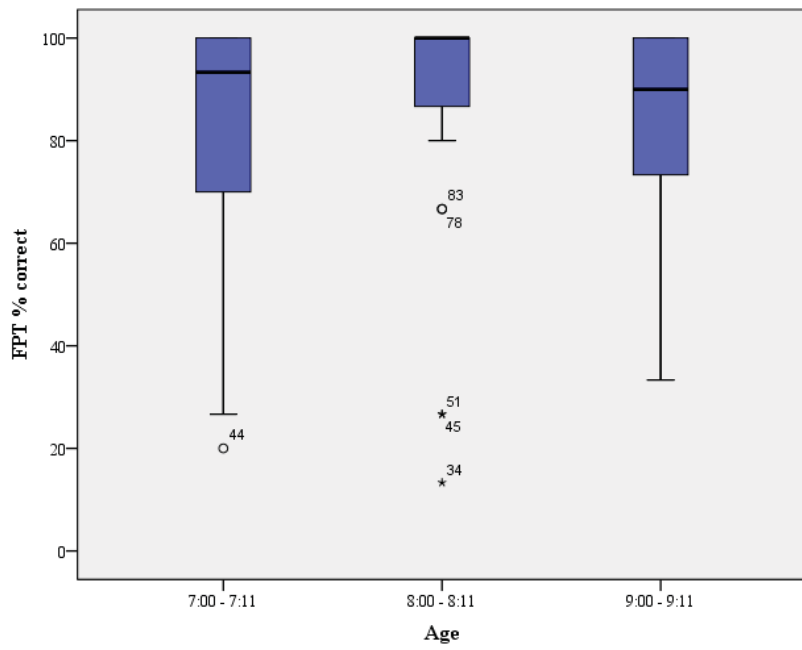
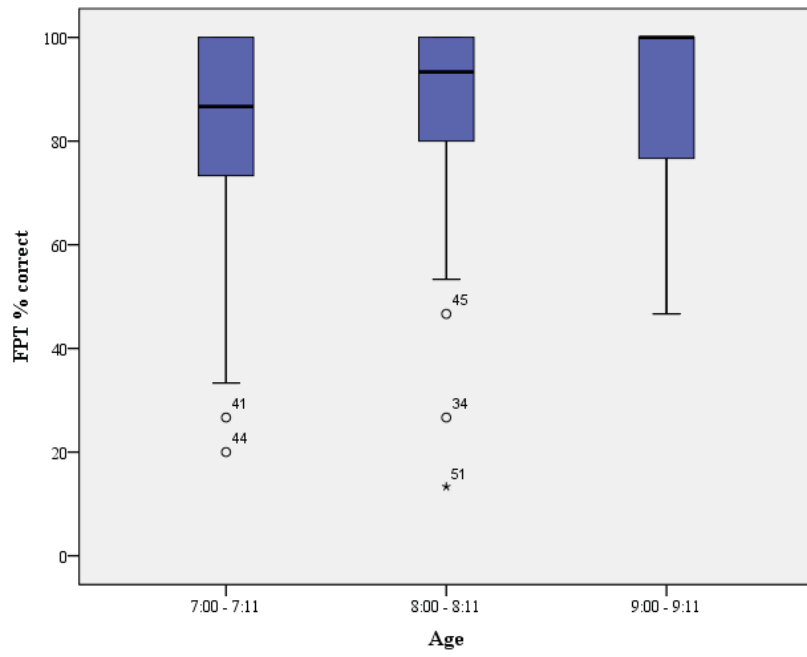


Figure 57 Graphical illustration of the median FPT % correct scores categorised by 'age group'

The data distribution of the two tests varied. While the DPT scores were mainly of a normal distribution, the data obtained from the FTP were non-normal, even following an attempt at normalising the data (see appendix C table 45). The one-way ANOVA was used to investigate the differences between the groups on the DPT. No statistically significant difference was found between the performance of each group in both ears: DPT RE= [F(2,98) = 1.500, p = .228]; LE = [F(2,98) = 1.673, p = .193].

The K-W test was used to investigate the effect of age on the FTP. Results also revealed no statistically significant difference between groups on this test: FPT RE (H(2) = 2.292, p=.318); LE (H(2) = 2.604, p=.272)⁴⁴.

5.3.4.2 *The effect of gender on the Duration and Frequency Patterns Tests.*

⁴⁴ The parametric equivalent was in agreement: FPT RE= [F(2,98) = 1.054, p = .353]; LE = [F(2,95) = 0.781, p = .461]

The male participants performed better than the females in both subtests for both ears (figures 5.39 and 5.40). The boxplots of the DPT (figure 58) demonstrate a variation in the scores obtained for both genders. The boxplots of the FPT display a different pattern, where the females' scores varied more than the males in both ears (figure 59).

Boxplot

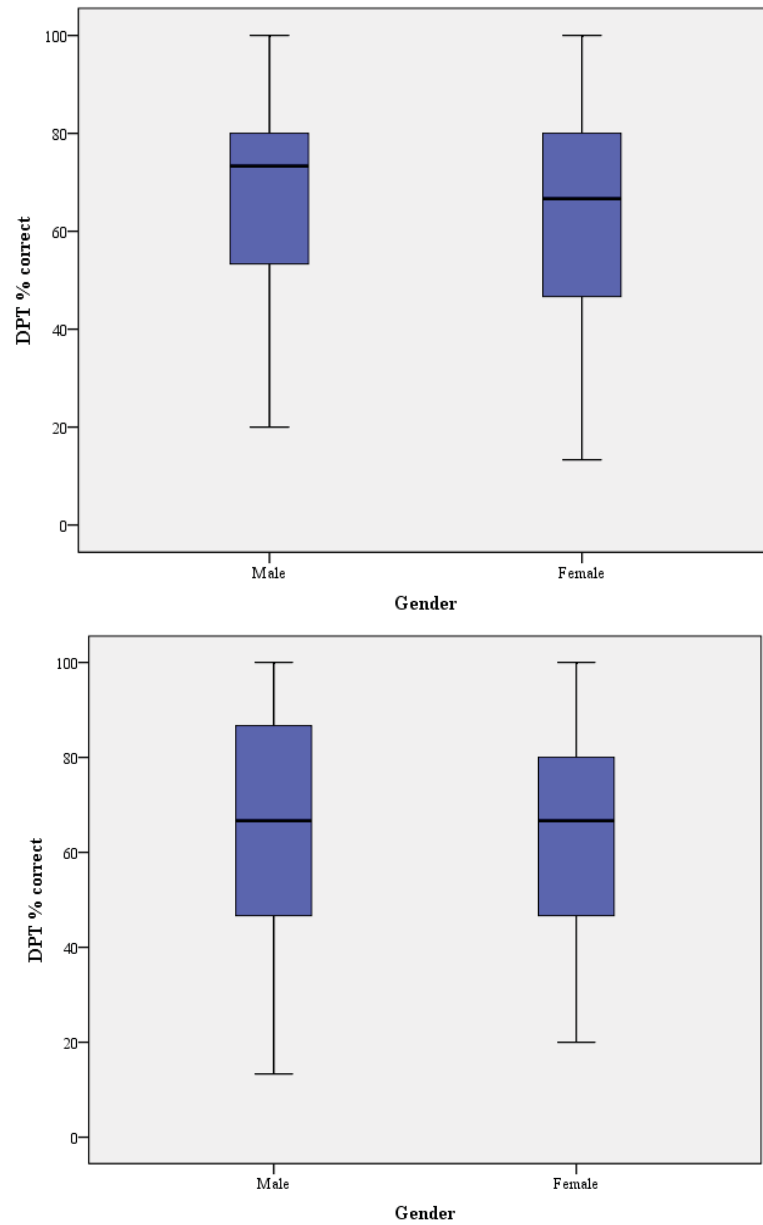


Figure 58 Graphical illustration of the median DPT % correct scores categorised by 'gender' for the right (above) and left (below) ears

Boxplot

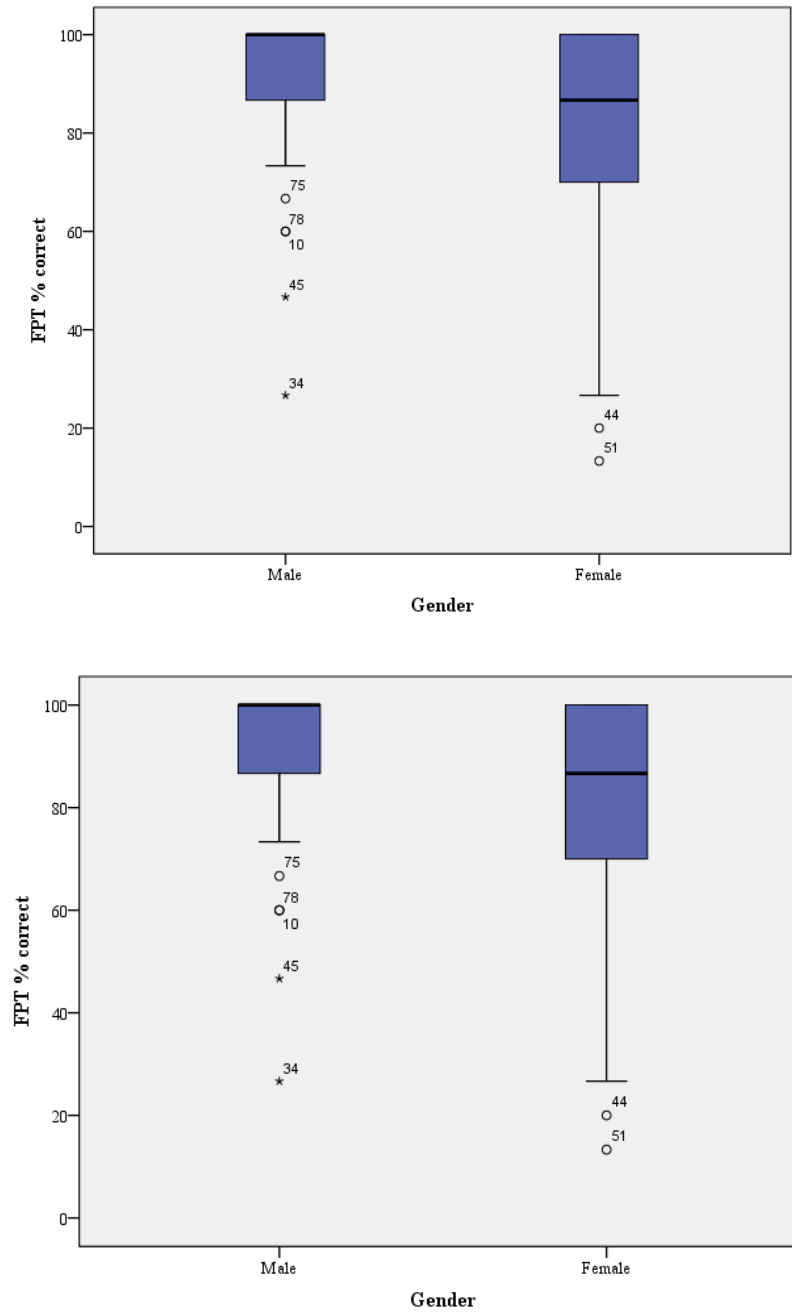


Figure 59 Graphical illustration of the median FPT % correct scores categorised by 'gender' for the right (above) and left (below) ears

The tests of normality (appendix 5 table 5.48) indicate primarily non-normal data. The M-W test found no statistically significant difference between groups in both subtests, although a near significant result emerged for the FTP in the right ear:

- DPT, right: $U=1096$, $p=.322$ between the ‘male’ (Mdn=73.3) and the ‘female’ (Mdn=66.7) groups
- DPT, left: $U=1165.5$, $p=.611$ between the ‘male’ (Mdn=66.7) and the ‘female’ (Mdn=66.7) groups
- FTP, right: $U=975.5$, $p=.055$ between the ‘male’ (Mdn=100) and the ‘female’ (Mdn=86.7) groups
- FTP, left: $U=963$, $p=.110$ between the ‘male’ (Mdn=100) and the ‘female’ (Mdn=93.3) groups⁴⁵

⁴⁵ The parametric equivalent (independent samples t-test) was in agreement –

- DPT, right: ‘male’ (M= 65.9, SD =21.5) and ‘female’ (M= 61.6, SD=22.2) groups: $t(99)= 0.971$, $p=.334$.
- DPT, left: ‘male’ (M= 65.6, SD =25.0) and ‘female’ (M= 64.3, SD=20.1) groups: $t(99)= 0.881$, $p=.779$.
- FPT, right: ‘male’ (M= 90.4, SD =16.5) and ‘female’ (M= 81.3, SD=22.9) groups: $t(98.9)= 2.098$, $p=.038$.
- FPT, left: ‘male’ (M= 88.9, SD =19.9) and ‘female’ (M= 82.5, SD=23.2) groups: $t(96)= 1.449$, $p=.151$.

5.3.4.3 *The effect of geographic region on the Duration and Frequency*

Patterns Tests.

The participants living in the North of the island scored higher than those living in the South. This pattern was evident in both ears of both subtests (figures 5.41 and 5.42). All the respective box plots demonstrate substantial overlap in the performance of the two groups, suggesting that the difference in mean scores between the groups might not be significant. Tables 49 and 50 of appendix C further augment these results.

Boxplot

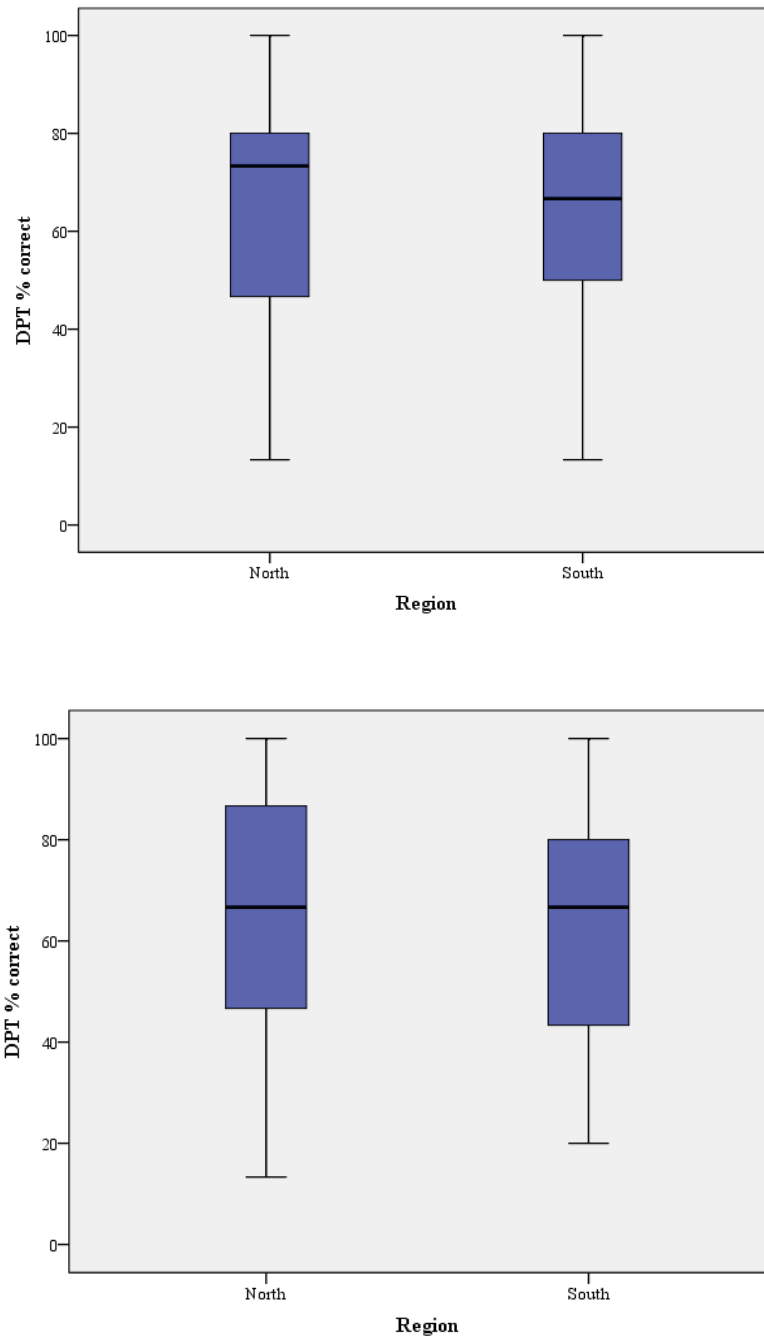
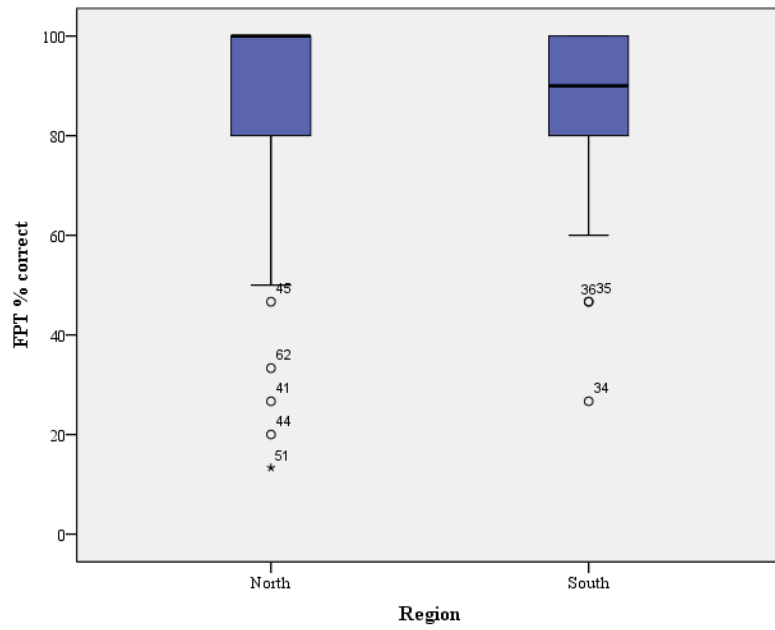


Figure 60 Graphical illustration of the median DPT % correct scores categorised by 'geographic region' for the right (above) and left (below) ears

Boxplot



Boxplot

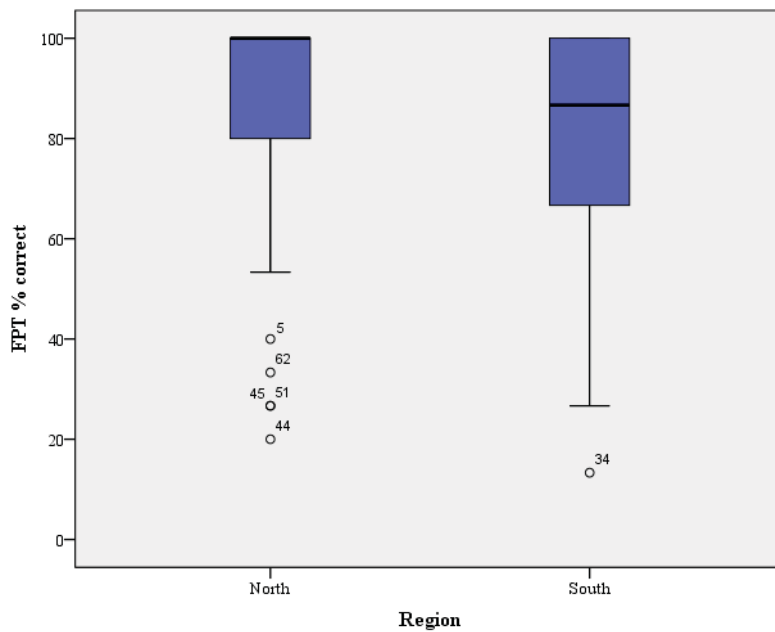


Figure 61 Graphical illustration of the median FPT % correct scores categorised by 'geographic region' for the right (above) and left (below) ears

The K-S and S-W tests of normality (appendix C table 51) present normally distributed data from the scores of participants living in the South, but non-normal data distribution from the participants living in the North in the DPT. An attempt to normalise the data still resulted in data of non-normal distribution.

The data obtained from the FPT were all non-normally distributed. Hence, the non-parametric test was used to examine the effect of ‘region’ on the performance of the DPT and FPT. This resulted in no statistically significant difference between groups:

- DPT, right: $U=881$, $p=.730$ between the ‘North’ (Mdn=73.3) and the ‘South’ (Mdn=66.7) groups
- DPT, left: $U=809.5$, $p=.359$ between the ‘North’ (Mdn=66.7) and the ‘South’ (Mdn=66.7) groups
- FTP, right: $U=755.5$, $p=.154$ between the ‘North’ (Mdn=100) and the ‘South’ (Mdn=90) groups
- FTP, left: $U=700.5$, $p=.094$ between the ‘North’ (Mdn=100) and the ‘South’ (Mdn=86.7) groups⁴⁶

5.3.4.4 The effect of school type on the Duration and Frequency Patterns Tests.

⁴⁶ The parametric equivalent (independent samples t-test) was in agreement –

- DPT, right: ‘North’ (M= 63.6, SD =22.3) and ‘South’ (M= 62.8, SD=21.1) groups: $t(99)= 0.150$, $p=.881$.
- DPT, left: ‘North’ (M= 65.8, SD =22.5) and ‘South’ (M= 61.7, SD=21.2) groups: $t(99)= 0.797$, $p=.427$.
- FPT, right: ‘North’ (M= 86.0, SD =21.1) and ‘South’ (M= 82.5, SD=20.3) groups: $t(99)= 0.690$, $p=.492$.
- FPT, left: ‘North’ (M= 87.1, SD =20.4) and ‘South’ (M= 79.2, SD=25.8) groups: $t(96)= 1.551$, $p=.124$.

The participants attending a state school obtained the poorest median scores in the DPT, while the best median scores were obtained from the participants attending an independent school (figure 62). This pattern was observed in both ears. From the box plots it is evident that despite the emerged median scores there was an amount of overlap in scores across the three groups.

Boxplot

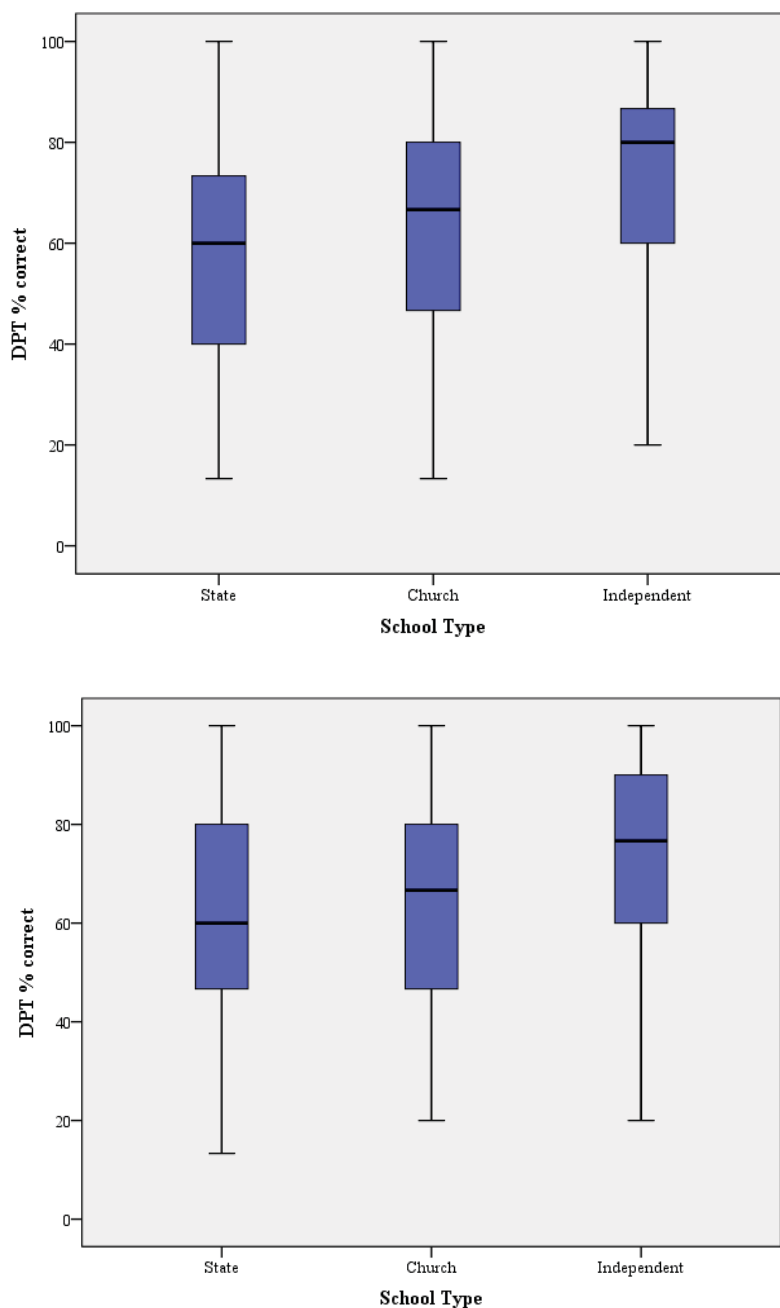


Figure 62 Graphical illustration of the median DPT % correct scores categorised by ‘school type’ for the right (above) and left (below) ears

The participants attending a state school also obtained the poorest median scores in the FTP, while those attending a church school scored best on average (figure 63). The box

plots show a substantial amount of overlap between each group. The scores from the 'state school' participants were also most varied, depicted by the longer whisker lines.

Boxplot

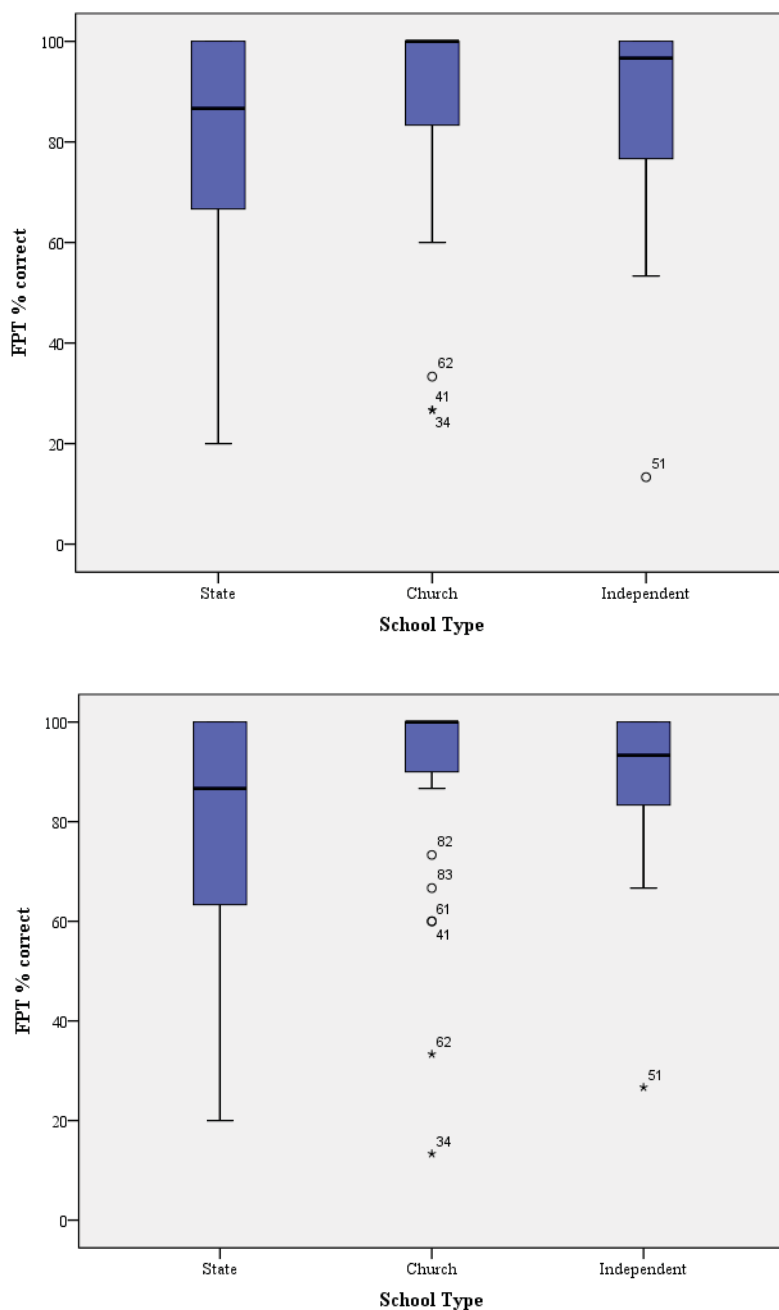


Figure 63 Graphical illustration of the median FPT % correct scores categorised by 'school type' for the right (above) and left (below) ears

The tests of normality (appendix C table 54) present overall normal distribution in the scores of the DPT test (with the exception of the ‘independent school’ group for the right ear) and non-normal distribution across all groups for the FPT test (even following an attempt to normalise the data). The one-way ANOVA was used to examine the effect of ‘school type’ on the performance in the DPT. A statistically significant difference was found between the performance of each group in the left ear: DPT = [F(2,98) = 3.358, p = .039]. No statistically significant difference emerged in the right ear: [F(2,98) = 2.555, p = .083]. Post-Hoc comparisons using the Tukey HSD test indicated that the left ear mean score of the ‘independent school’ group (M=73.33, SD=21.89) differed significantly from the ‘state school’ group (M=59.02, SD=22.34). The ‘church school’ group (M=65.74, SD=20.67) did not differ significantly from the other two groups. The K-W test was used to investigate the effect of ‘school type’ on the performance in the FPT. No statistically significant difference was found between groups for both ears: FPT RE (H(2) = 1.941, p=.379); LE (H(2) = 3.694, p=.158)⁴⁷.

⁴⁷ The parametric equivalent was in agreement: FPT RE= [F(2,98) = 0.718, p = .490]; LE = [F(2,95) = 2.781, p = .067]

5.3.4.5 The effect of primary language on the Duration and Frequency Patterns

Tests.

In the DPT, the participants who used English as their primary language scored higher on average than those who used Maltese (figure 64). However, the boxplots demonstrate variation and overlap between the scores obtained from the both groups.

Boxplot

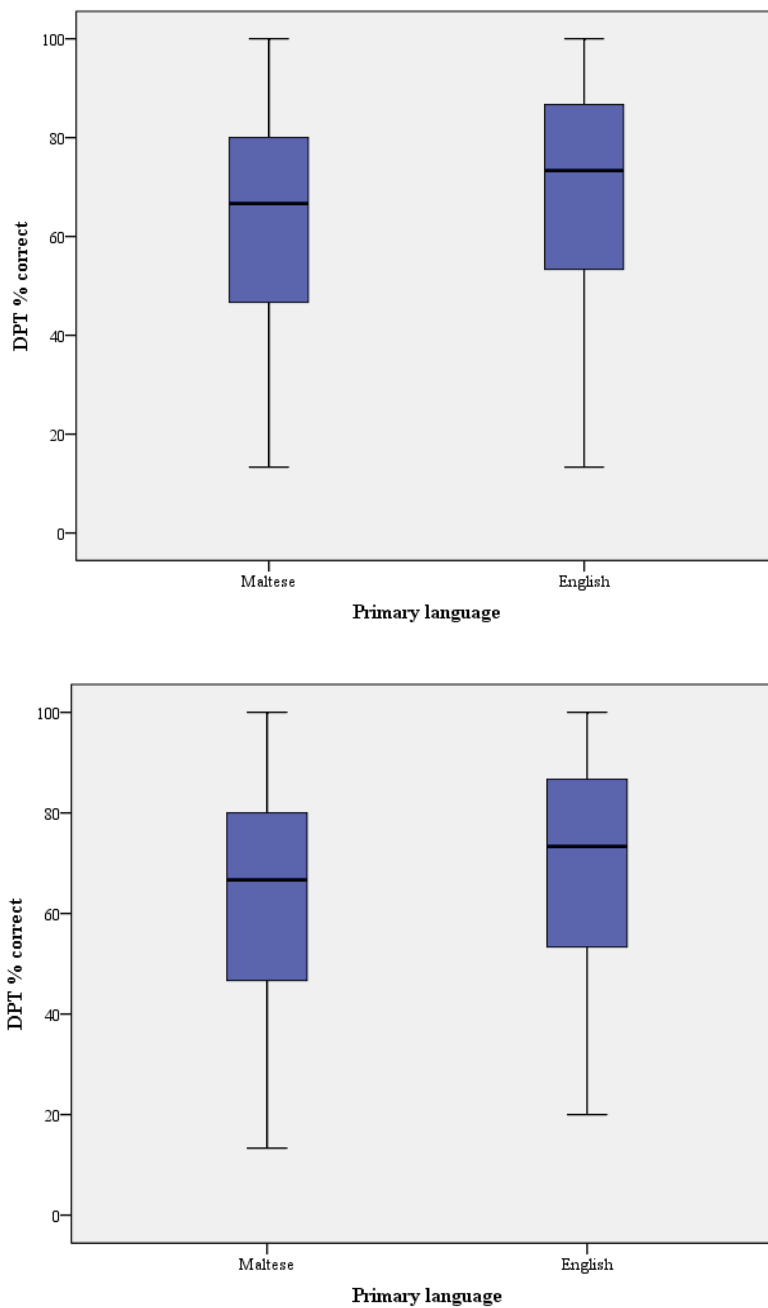


Figure 64 Graphical illustration of the median DPT % correct scores categorised by 'primary language' for the right (above) and left (below) ears

In the FPT, a similar median score was obtained by the two groups in the right ear. However, the children who used English as their primary language obtained better median scores in the left ear. Nevertheless, overlap in the scores obtained from the two groups was evident (figure 65).

Boxplot

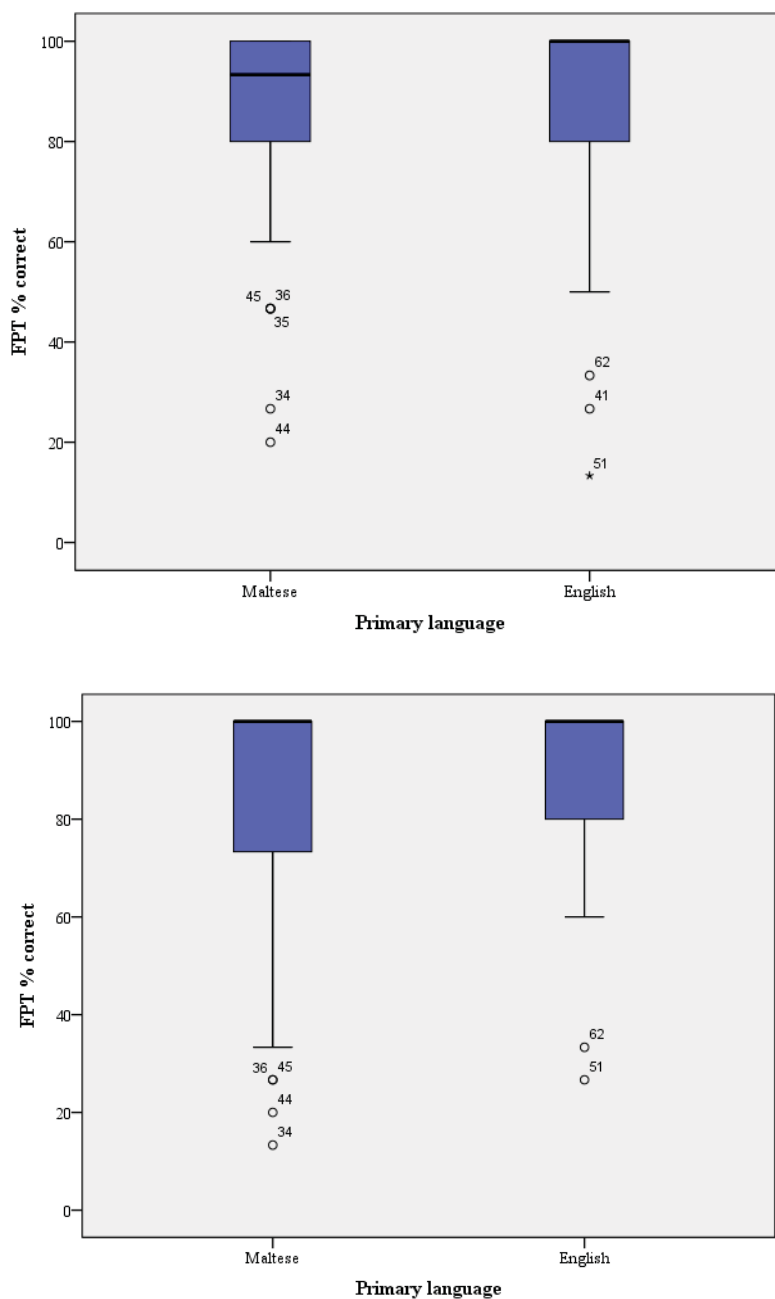


Figure 65 Graphical illustration of the median FPT % correct scores categorised by 'primary language' for the right (above) and left (below) ears

The K-S and S-W tests of normality (appendix C table 57) clearly indicate data of non-normal distribution obtained from the FPT. The data that emerged from the DPT were non-normal for the right ear but normal for the left ear. The M-W test was used to test the effect of ‘primary language’ on the FPT and the right ear of the DPT. The independent samples t-test was used to test the effect of ‘primary language’ on the left ear of the DPT. These results indicate no statistically significant difference between groups on the tests:

- DPT, right: $U=969.5$, $p=.062$ between the ‘Maltese’ (Mdn=66.7) and the ‘English’ (Mdn=73.3) groups⁴⁸
- DPT, left: ‘Maltese’ (M= 62.7, SD =22.1) and ‘English’ (M= 67.8, SD=22.2) groups: $t(99)= -1.134$, $p=.259$
- FPT, right: $U=1136.5$, $p=.456$ between the ‘Maltese’ (Mdn=93.3) and the ‘English’ (Mdn=100) groups
- FPT, left: $U=1050.5$, $p=.359$ the ‘Maltese’ (Mdn=100) and the ‘English’ (Mdn=100) groups⁴⁹

5.4.4.6 The effect of pathology on the Duration and Frequency Patterns Tests.

In the DPT, the clinical group were found to perform worse than the TD group.

This difference is presented in figure 66 and further elaborated numerically in the descriptive

⁴⁸ The parametric equivalent (independent samples t-test) was in agreement –

- DPT, right: ‘Maltese’ (M= 60.2, SD =21.7) and ‘English’ (M= 67.8, SD=21.6) groups: $t(99)= -1.727$, $p=.087$.

⁴⁹ The parametric equivalent (independent samples t-test) was in agreement –

- FPT, right: ‘Maltese’ (M= 85.3, SD =19.5) and ‘English’ (M= 85.0, SD=22.8) groups: $t(99)= -0.109$, $p=.913$.
- FPT, left: ‘Maltese’ (M= 82.5, SD =24.5) and ‘English’ (M= 88.9, SD=17.5) groups: $t(96)= -1.529$, $p=.130$.

statistics in table 58 of appendix C, where the difference in the mean scores of the two groups was calculated to be 16.4% in the right ear and 18.2% in the left. This difference is also evident through the boxplots in figure 66.

Boxplot

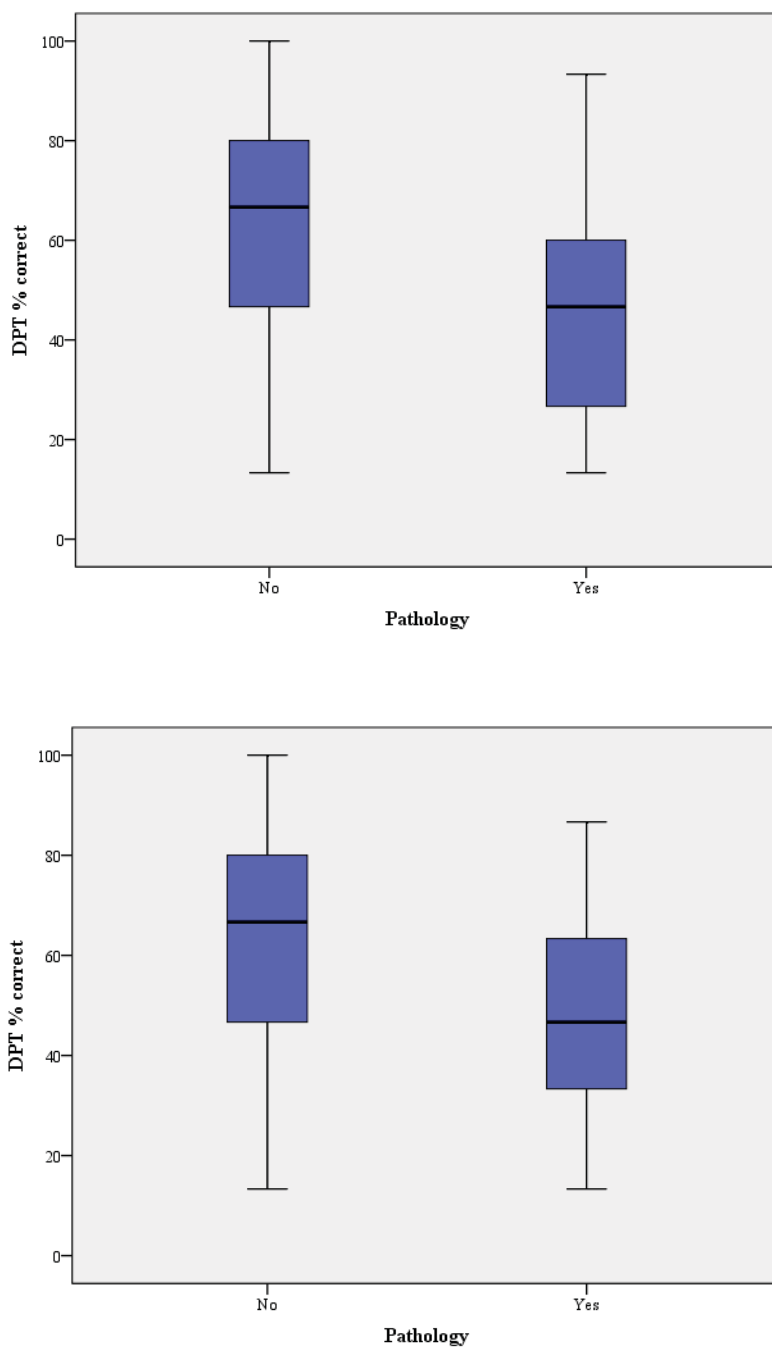


Figure 66 Graphical illustration of the median DPT % correct scores categorised by 'pathology' for the right (above) and left (below) ears

In contrast to the outcome of the DPT, the clinical group were found to bilaterally score better than the TD participants on the FPT (see figure 67 and the descriptive statistics in appendix C table 59).

Boxplot

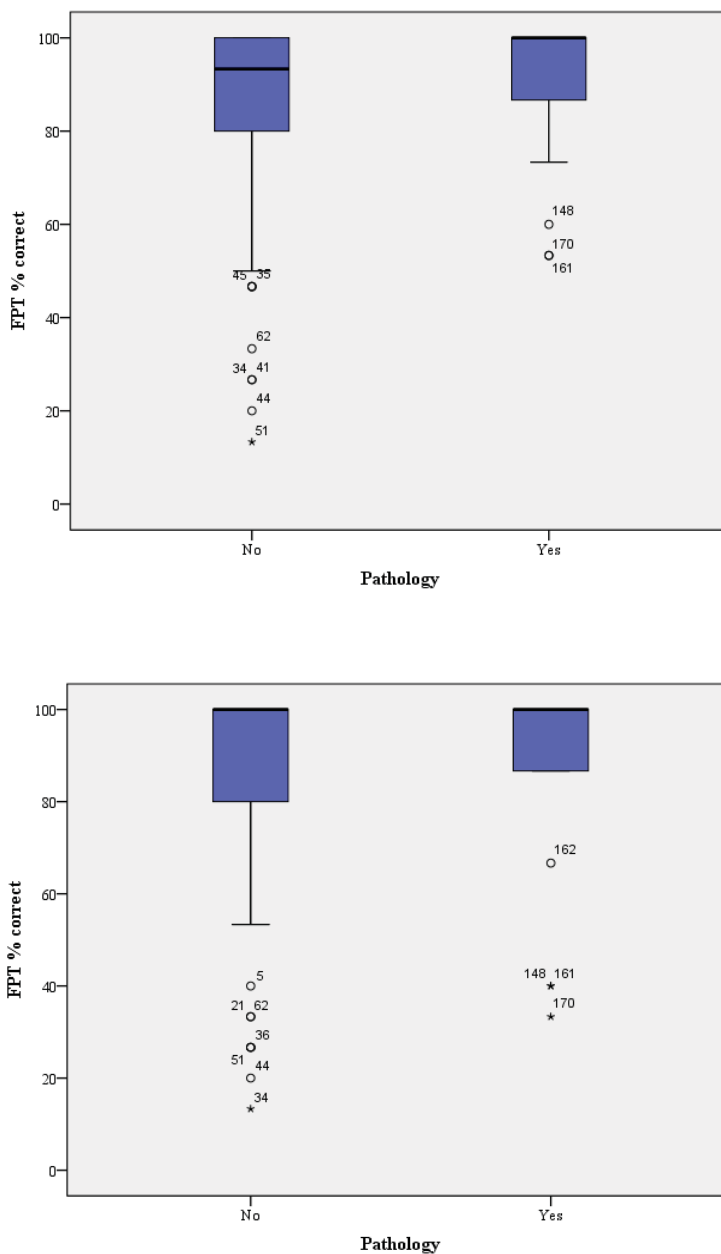


Figure 67 Graphical illustration of the median FPT % correct scores categorised by 'pathology' for the right (above) and left (below) ears

The tests of normality (appendix C table 60) indicate data of non-normal distribution in the FPT. The DPT differed, with the data obtained from the clinical group being normally distributed and the data from the TD group being of a non-normal distribution. The M-W test was used to test the effect of ‘pathology’ on the FPT and DPT. These results indicate no statistically significant difference between groups on the FTP but a statistically significant difference between them on the DPT:

- DPT, right: $U=835.5$, $p=.002$ between the ‘no pathology’ (Mdn= 66.67) and the ‘pathology’ (Mdn= 46.67) groups
- DPT, left: $U=757.5$, $p < .001$ between the ‘no pathology’ (Mdn= 66.67) and the ‘pathology’ (Mdn= 46.67) groups
- FTP, right: $U=1098$, $p=.395$ between the ‘no pathology’ (Mdn= 93.33) and the ‘pathology’ (Mdn= 100) groups
- FTP, left: $U=1143.5$, $p=.580$ between the ‘no pathology’ (Mdn= 100) and the ‘pathology’ (Mdn= 100) groups⁵⁰

⁵⁰ The parametric equivalent (independent samples t-test) was in agreement –

- DPT, right: ‘no pathology’ (M= 63.4, SD =21.9) and ‘pathology’ (M= 47.0, SD=23.2) groups: $t(126)= 3.420$, $p=.001$.
- DPT, left: ‘no pathology’ (M= 64.8, SD =22.2) and ‘pathology’ (M= 46.7, SD=20.3) groups: $t(126)= 3.308$, $p=.002$.
- FPT, right: ‘no pathology’ (M= 85.1, SD =20.8) and ‘pathology’ (M= 89.3, SD=15.6) groups: $t(121)= -0.940$, $p=.349$.
- FPT, left: ‘no pathology’ (M= 85.2, SD =22.0) and ‘pathology’ (M= 88.3, SD=20.5) groups: $t(121)= -0.637$, $p=.525$.

5.3.5 Sub-tests using non-linguistic content: Gaps-in-Noise test

5.3.5.1 *The effect of age group on the Gaps-in-Noise test*

The youngest age group (7;00 – 7;11 years) performed weakest in both the right and left ears when scored in terms of smallest gap detected (Ath) and percentage correct (as is demonstrated in figures 5.49 and 5.50). A greater range in scores was also evident in the right ear of the youngest group. These results are further explained in the descriptive statistics (appendix C tables 61 and 62).

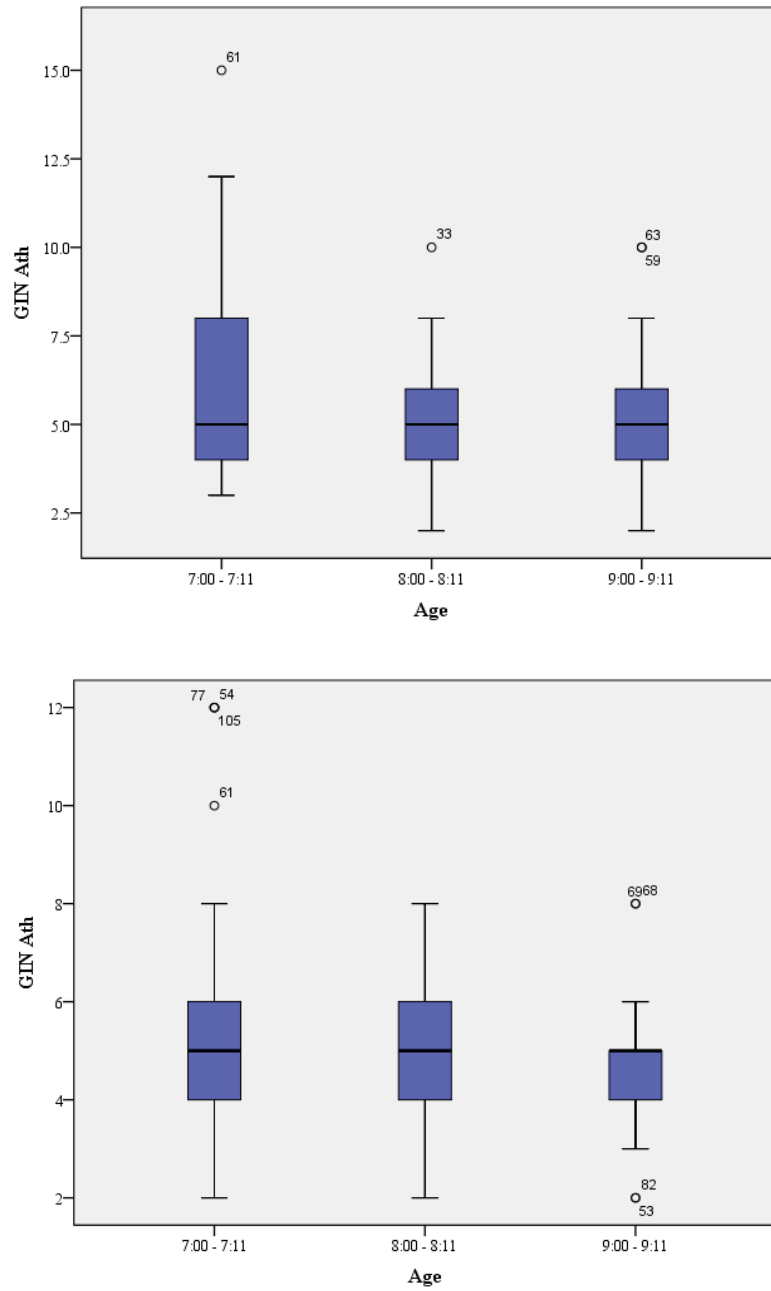


Figure 68 Graphical illustration of the median GIN Ath scores categorised by 'age group' for the right (above) and left (below) ears

Boxplot

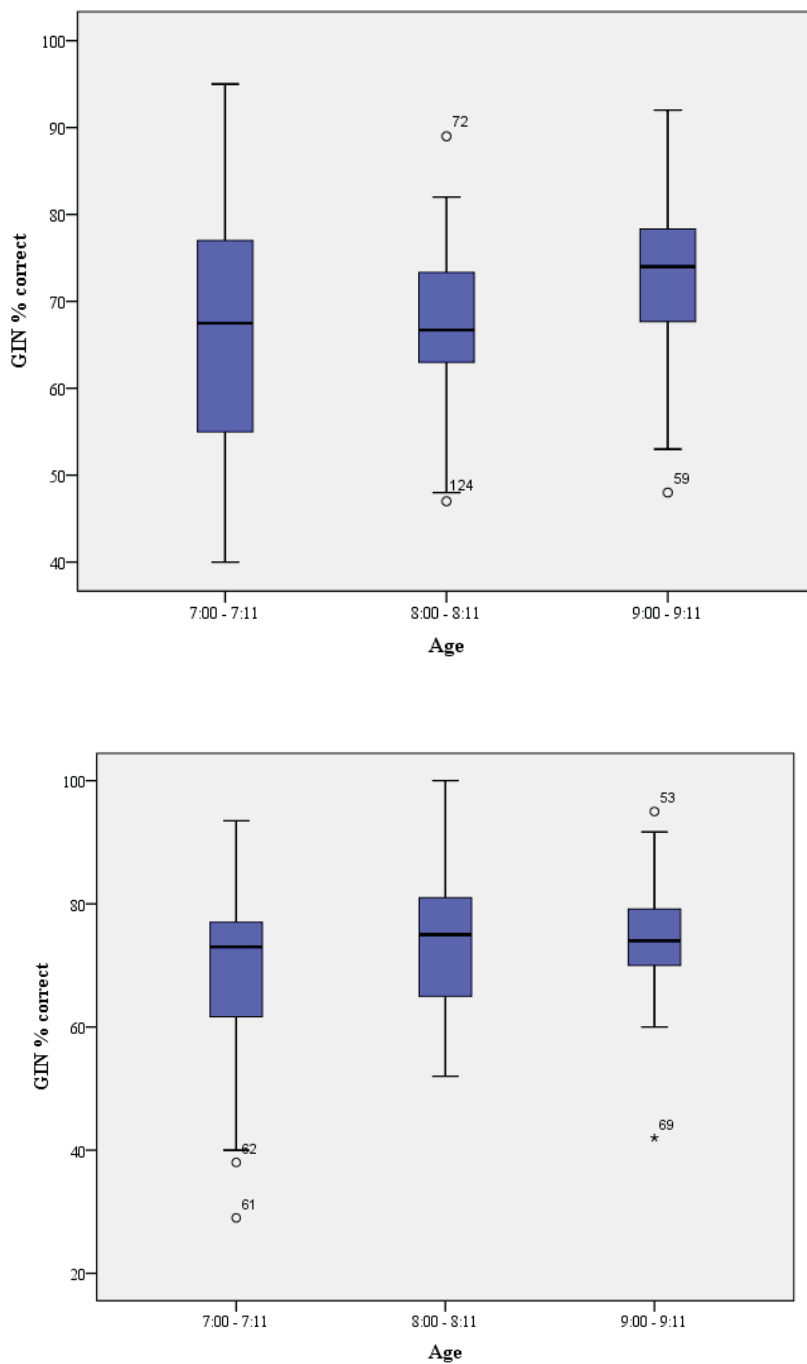


Figure 69 Graphical illustration of the median GIN % correct scores categorised by 'age group' for the right (above) and left (below) ears

The tests of normality (appendix C table 63) show that when the data were scored in terms of *Ath* they were of a non-normal distribution (even after logarithmic transformation in an attempt to normalise the data). On the other hand, the data scored in terms of *percentage correct* were normally distributed (with the exception of the 7;00 – 7;11 year old group results from the left ear). The K-W test was used to investigate the effect of ‘age’ on the performance in the GIN scored in terms of *Ath*. No statistically significant difference was found between groups for both ears: RE ($H(2) = 1.294, p = .524$); LE ($H(2) = 5.312, p = .070$)⁵¹.

The one-way ANOVA investigated the effect of ‘age’ on the performance in the GIN scored in terms of *percentage correct*. A statistically significant difference was found between the performance of each group in the right ear: GIN = [$F(2,127) = 4.035, p = .020$]. No statistically significant difference emerged in the left ear: [$F(2,98) = 2.109, p = .126$]. Post-Hoc comparisons for the right ear using the Tukey HSD test indicated that the mean score of the ‘7;00 – 7;11 year old’ group ($M=66.47, SD=13.54$) differed significantly from the ‘9;00 – 9;11 year old’ group ($M=73.14, SD=9.49$). The ‘8;00-8;11 year old’ group ($M=67.54, SD=9.40$) also differed significantly from the ‘9;00 – 9;11 year old’ group.

5.3.5.2 *The effect of gender on the Gaps-in-noise test*

Similar scores on the GIN test were obtained by the male and female participants, with the males obtaining slightly better scores overall. A greater variability in left ear scores

⁵¹ The parametric equivalent was in agreement for the RE but not for the LE: RE = [$F(2,127) = 1.975, p = .143$]; LE = [$F(2,127) = 5.107, p = .007$]

was also evident in the female group, as is demonstrated through the box plots of figures 5.51 and 5.52.

Boxplot

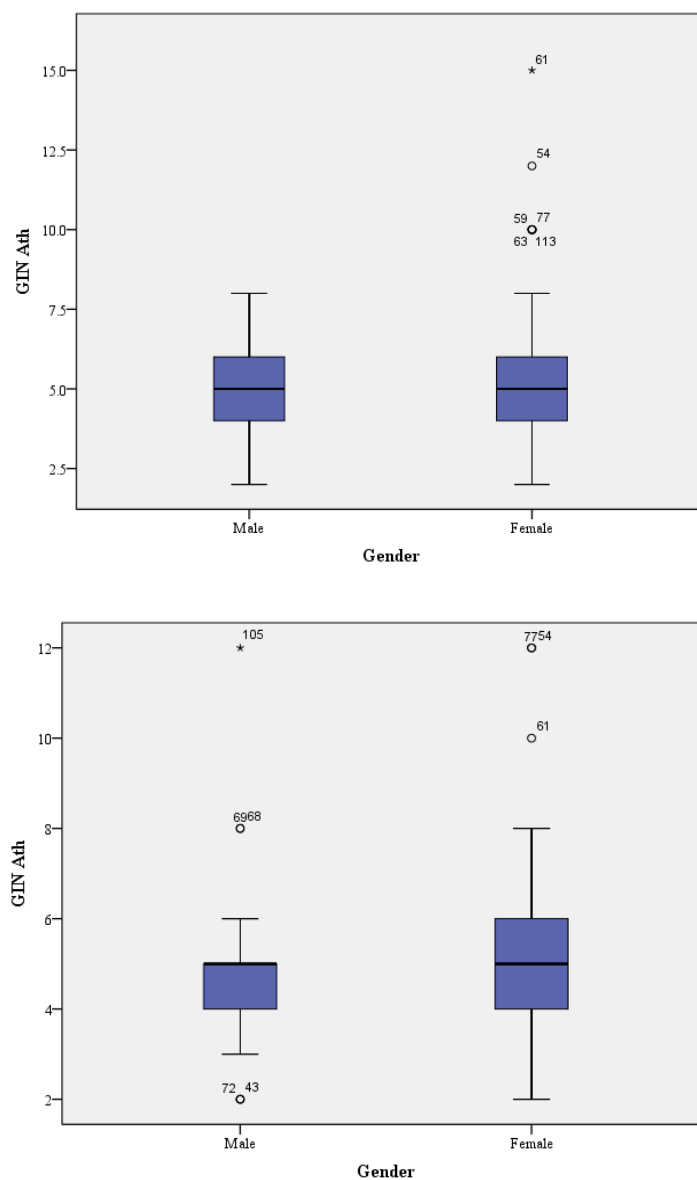


Figure 70 Graphical illustration of the median GIN Ath scores categorised by ‘gender’ for the right (above) and left (below) ears

Boxplot

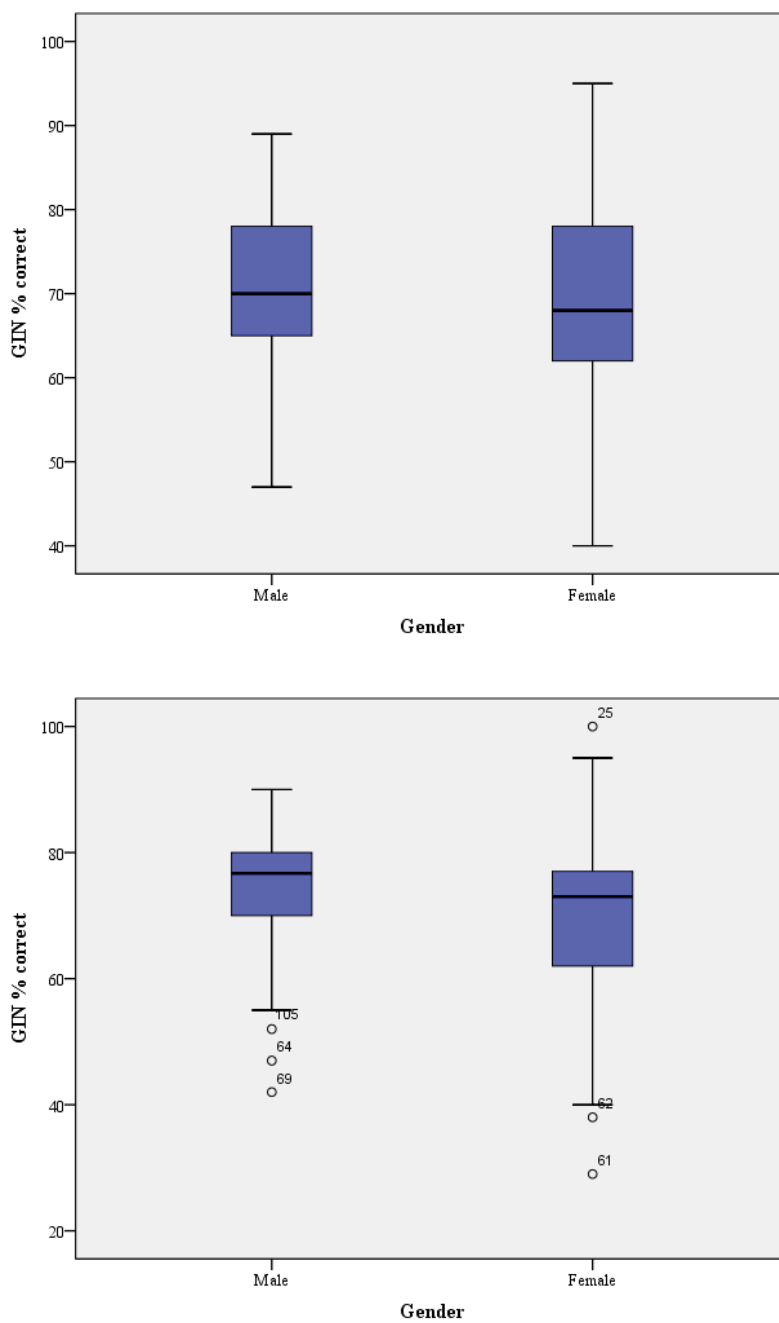


Figure 71 Graphical illustration of the median GIN % correct scores categorised by 'gender' for the right (above) and left (below) ears

The K-S and S-W tests of normality (appendix C table 66) indicate overall data of non-normal distribution, with the exception of the *percentage correct* data for the right ear in both groups. The M-W test was performed on the GIN test scored by *Ath* for both ears, and scored by *percentage correct* for the left ear. This did not expose a statistically significant difference between gender for all results; RE GIN (*Ath*): $U=1237$, $p=.161$ between the ‘male’ (Mdn=5.00) and the ‘female’ (Mdn=5.00) groups; LE GIN (*Ath*): $U=1216.5$, $p=.122$ between the ‘male’ (Mdn=5.00) and the ‘female’ (Mdn=5.00) groups; LE GIN (% correct): $U=1156.5$, $p=.063$ between the ‘male’ (Mdn=76.7) and the ‘female’ (Mdn=73.0) groups⁵². The independent samples t-test was computed for the GIN (% correct) on the right ear; male ($M=70.59$, $SD=9.58$) and female ($M=67.82$, $SD=12.32$): $t(108)=-1.267$, $p=.208$.

⁵² The parametric equivalent was generally in agreement except in the RE *Ath* result:

RE *Ath*; male ($M=4.80$, $SD=1.29$) and female ($M=5.65$, $SD=2.46$): $t(101.6)=-2.347$, $p=.021$.

LE *Ath*; male ($M=4.87$, $SD=1.67$) and female ($M=5.26$, $SD=1.91$): $t(108)=-1.119$, $p=.266$.

LE % correct; male ($M=73.96$, $SD=10.56$) and female ($M=70.32$, $SD=13.43$): $t(108)=1.519$, $p=.132$.

5.4.5.3 *The effect of geographic region on the Gaps-in-noise test*

On analysing the GIN scores in terms of ‘geographic region’ similar scores once again emerged between the two groups, as is revealed through the box plots of figures 72 and 73. However, a pattern did emerge of slightly lower scores obtained from the group living in the South of the island (refer to mean scores in appendix C tables 67 and 68).

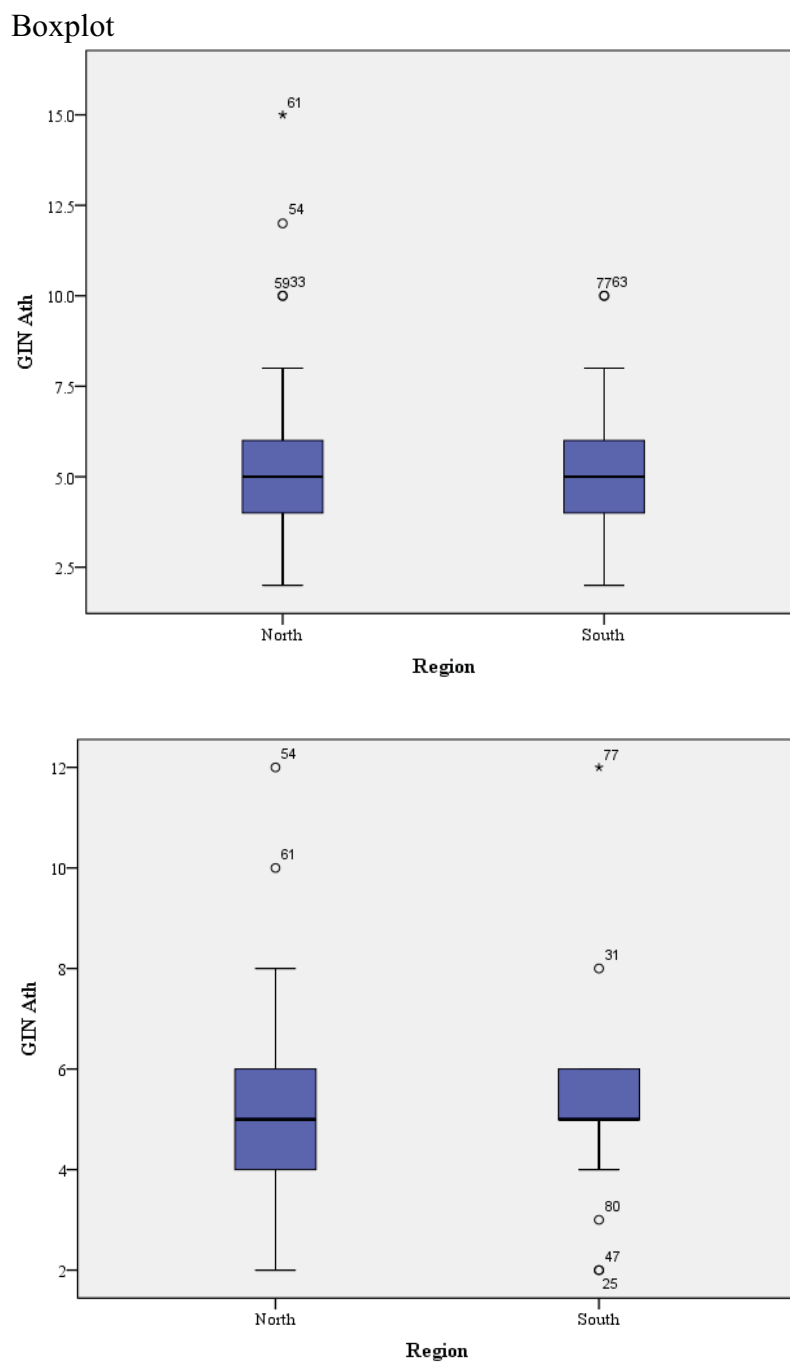
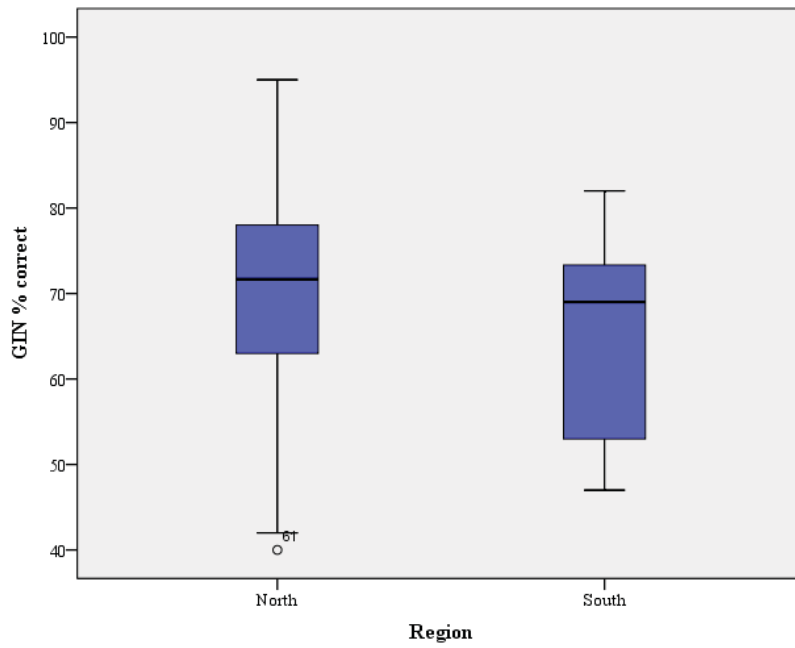


Figure 72 Graphical illustration of the median GIN Ath scores categorised by 'geographic region' for the right (above) and left (below) ears

Boxplot



Boxplot

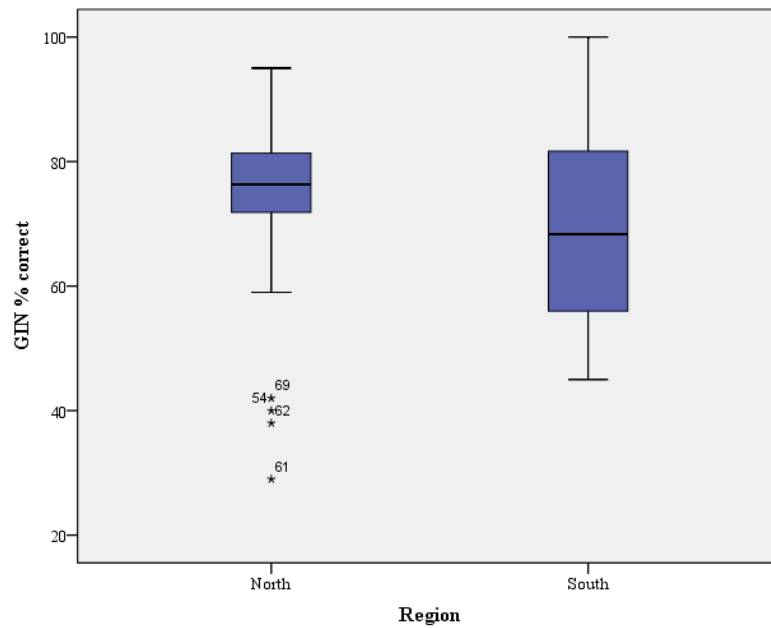


Figure 73 Graphical illustration of the median GIN % correct scores categorised by ‘geographic region’ for the right (above) and left (below) ears

The data obtained from the group living in the South were mainly normally distributed (with the exception of the *Ath* scores from the left ear), while the data obtained from the group living in the North were generally of a non-normal distribution (excluding the % correct scores from the right ear). An attempt at normalising the data did not yield results of a normal distribution (refer to appendix C table 69).

The M-W, implemented on the GIN test scored by *Ath* for both ears and scored by *percentage correct* for the left ear, resulted in no statistically significant difference between region for all results; RE GIN (*Ath*): $U=439.5$, $p=.972$ between the 'North' (Mdn=5.00) and the 'South' (Mdn=5.00) groups; LE GIN (*Ath*): $U=364.5$, $p=.263$ between the 'North' (Mdn=5.00) and the 'South' (Mdn=5.00) groups; LE GIN (% correct): $U=369$, $p=.309$ between the 'North' (Mdn=76.33) and the 'South' (Mdn=68.33) groups⁵³. The independent samples t-test, carried out on the GIN (% correct) scores for the right ear also yielded no statistically significant difference between groups; North ($M= 69.57$, $SD =12.86$) and South ($M= 66.20$, $SD=11.59$): $t(67)=1.142$, $p=.258$.

⁵³ The parametric equivalent was in agreement:

RE *Ath*; North ($M= 5.52$, $SD =2.42$) and South ($M= 5.47$, $SD=2.21$): $t(67)=.073$, $p=.972$.

LE *Ath*; North ($M= 4.96$, $SD =1.91$) and South ($M= 5.41$, $SD=2.29$): $t(67)=-.803$, $p=.425$.

LE % correct; North ($M= 74.14$, $SD =13.25$) and South ($M= 69.69$, $SD=16.01$): $t(67)=1.142$, $p=.258$.

5.3.5.4 *The effect of school type on the Gaps-in-noise test*

The participants attending a state school obtained the poorest mean scores on the GIN test; both in terms of *Ath* and *percentage correct* scores. The children attending a church school attained the best mean *Ath* scores while those attending an independent school achieved the best median *percentage correct* scores (figures 74 and 75). Nevertheless, a fair amount of overlap was still evident between the scores of the three groups as is illustrated in the boxplots.

Boxplot

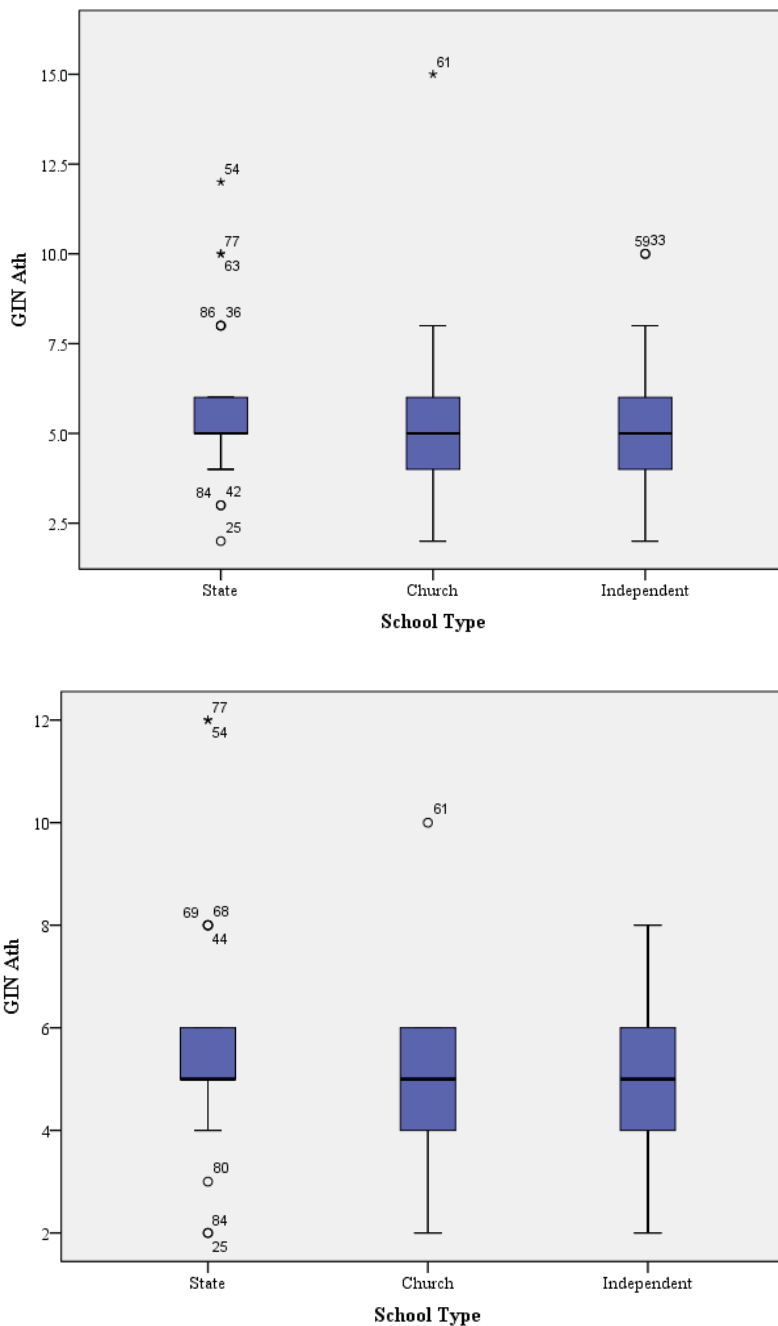


Figure 74 Graphical illustration of the median GIN Ath scores categorised by ‘school type’ for the right (above) and left (below) ears

Boxplot

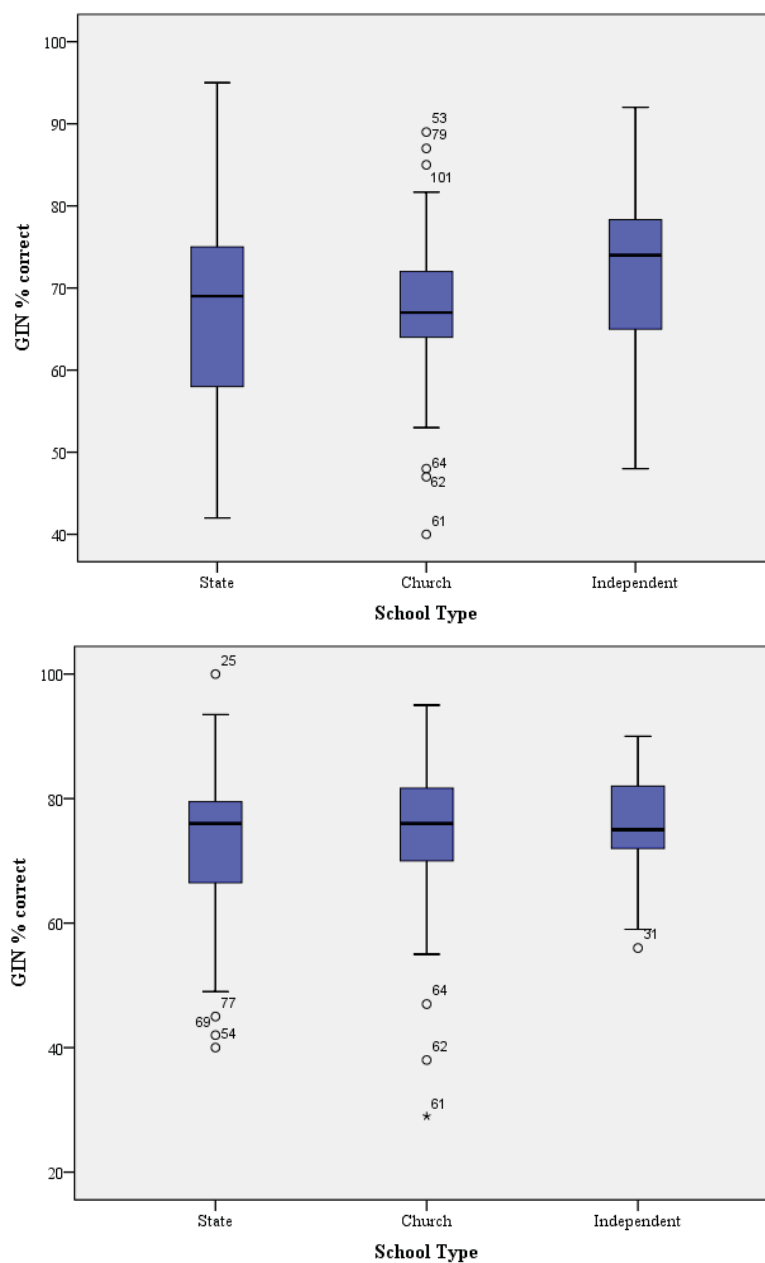


Figure 75 Graphical illustration of the median GIN % correct scores categorised by 'school type' for the right (above) and left (below) ears

The tests of normality exposed data of both normal and non-normal distribution across the GIN *Ath* and *percentage correct* subtest scores for the right and left ears (appendix

C table 72). The Kruskal-Wallis test was used to investigate the effect of ‘school type’ on the performance in the GIN test scored in terms of *Ath*. Although the group attending a state school was found to display a lower mean score than the other two groups, there was no statistically significant difference (RE GIN (Ath): $H(2) = 1.787$, $p = .409$; LE GIN (Ath): $H(2) = 2.288$, $p = .318$). An ANOVA was run to compare the effect of school type on the GIN *percentage correct* scores. The result showed no statistically significant difference between groups in both right and left sides [RE GIN (% correct): $[F(2,66) = .782$, $p = .462$; LE GIN (% correct): $[F(2,66) = .286$, $p = .752]$ ⁵⁴.

5.3.5.5 *The effect of primary language on the Gaps-in-noise test*

The participants who used English as their primary language were noted to perform marginally better than the children who spoke primarily Maltese (as illustrated in figures 5.57 and 5.58).

Boxplot

⁵⁴ The parametric equivalent was in agreement:
 RE GIN (Ath): $[F(2,66) = .508$, $p = .604$.
 LE GIN (Ath): $[F(2,66) = 1.864$, $p = .163$

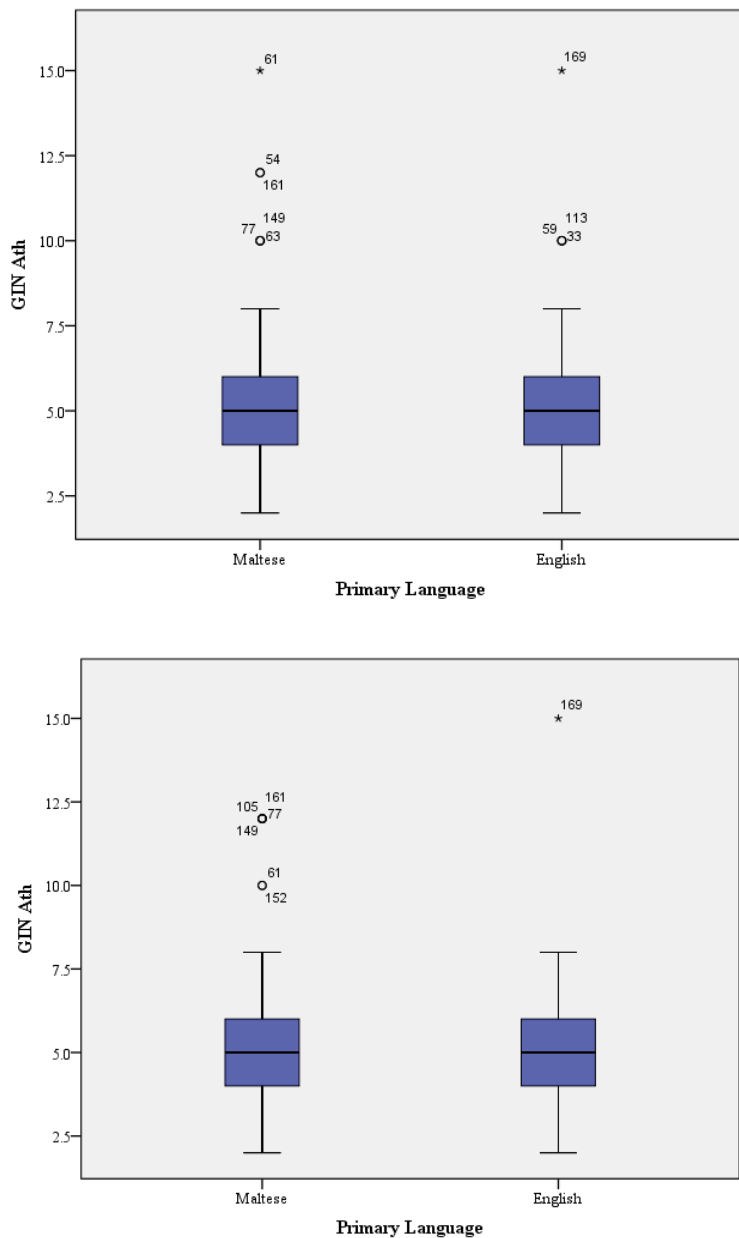


Figure 76 Graphical illustration of the median GIN Ath scores categorised by ‘primary language’ for the right (above) and left (below) ears

Boxplot

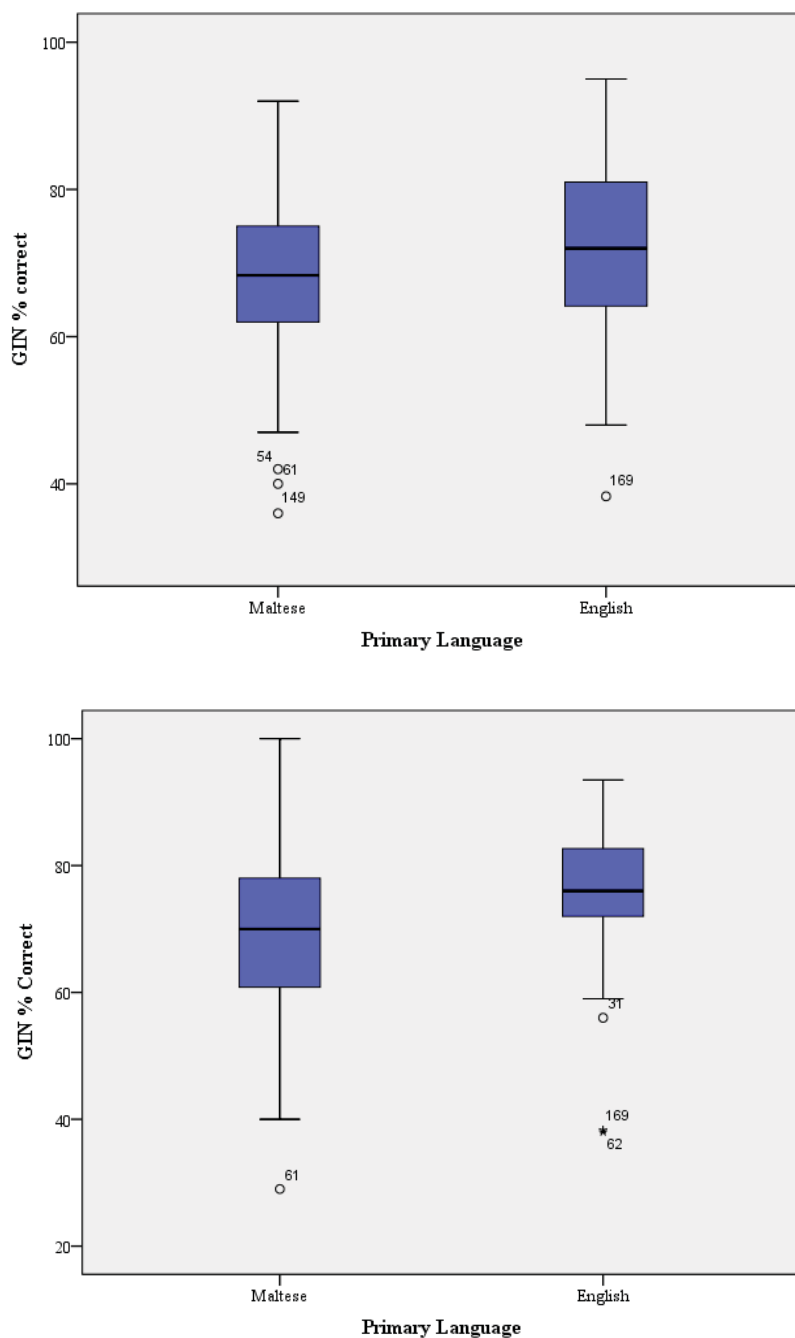


Figure 77 Graphical illustration of the median GIN % correct scores categorised by ‘primary language’ for the right (above) and left (below) ears

The tests of normality exposed data of primarily non-normal distribution across groups, with the exception of GIN *percentage correct* score in the left ear from both groups

(appendix C table 75). The M-W was used to investigate the effects of *primary language* on the performance in the GIN subtest in terms of *Ath* for both ears and *percentage correct* for the right ear. No statistically significant difference emerged between the two groups for these subtests; RE GIN (*Ath*): $U=1327.5$, $p=.795$ between the ‘Maltese’ (Mdn=5.00) and the ‘English’ (Mdn=5.00) groups; LE GIN (*Ath*): $U=1165.0$, $p=.187$ between the ‘Maltese’ (Mdn=5.00) and the ‘English’ (Mdn=5.00) groups; RE GIN (% correct): $U=1118.5$, $p=.117$ between the ‘Maltese’ (Mdn=68.67) and the ‘English’ (Mdn=72.00) groups⁵⁵. The independent samples t-test was carried out on the GIN *percentage correct* scores for the left ear, where a statistically significant difference emerged between groups; ‘Maltese’ (M= 69.73, SD =12.75) and ‘English’ (M= 75.74, SD=10.86): $t(108) = -2.470$, $p= .015$.

5.3.5.6 *The effect of pathology on the Gaps-in-noise test*

When comparing the performance of the TD children with the clinical group, results showed poorer median scores from the latter group in for both ears when scored in

⁵⁵ The parametric equivalent was in agreement:

RE *Ath*; Maltese (M= 5.32, SD =2.13) and English (M= 5.26, SD=2.10): $t(108)=.133$, $p=.894$.

LE *Ath*; Maltese (M= 5.33, SD =1.98) and English (M= 4.66, SD=1.4): $t(108)= 1.870$, $p=.064$.

RE % correct: Maltese (M= 67.64, SD =10.87) and English (M= 71.45, SD=11.86): $t(108)=-1.693$, $p=.093$.

terms of *Ath*, and on the right side when scored in terms of *percentage correct*. This group also displayed greater variability in scores when compared with the TD group (as is evident through the boxplots of figures 78 and 79).

Boxplot

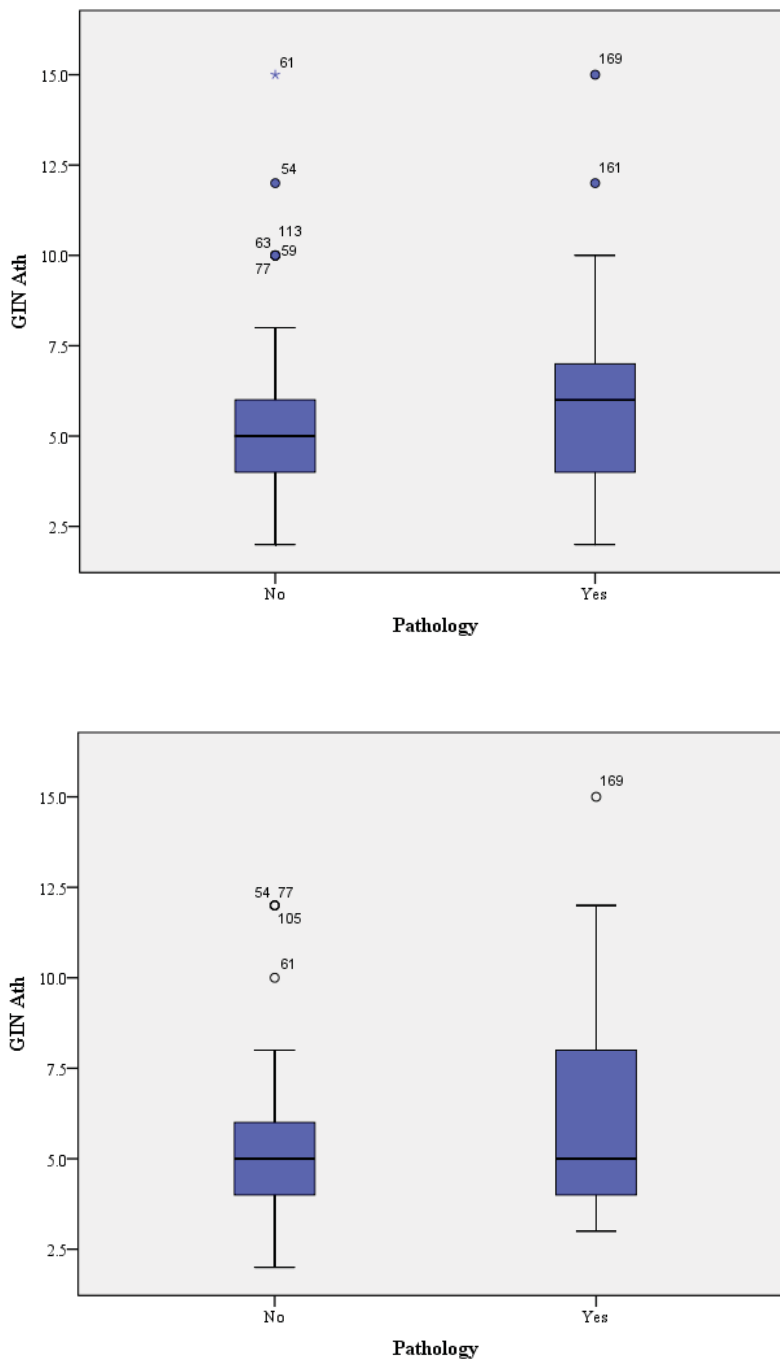


Figure 78 Graphical illustration of the median GIN Ath scores categorised by ‘pathology’ for the right (above) and left (below) ears

Boxplot

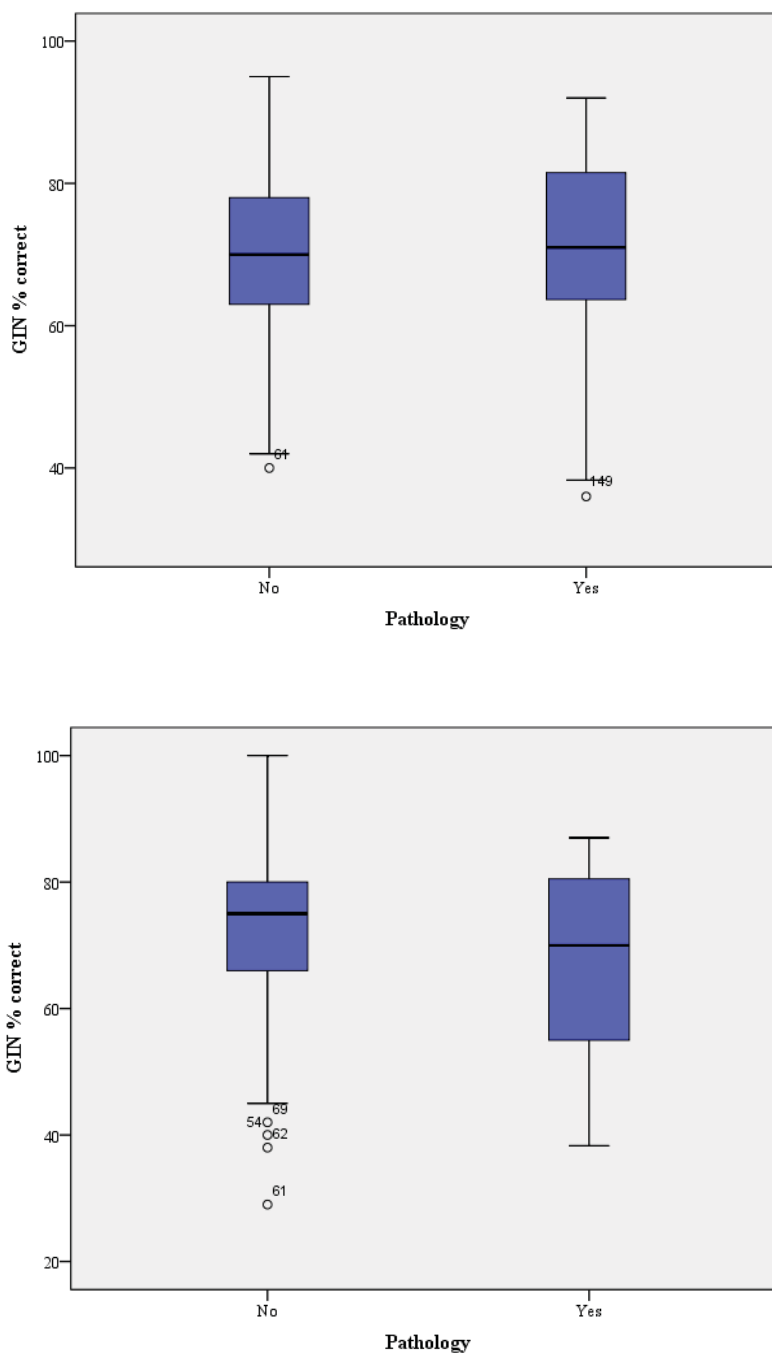


Figure 79 Graphical illustration of the median GIN % correct scores categorised by 'pathology' for the right (above) and left (below) ears

The tests of normality depict data of non-normal distribution for the GIN Ath scores and normally distributed data for the GIN percentage correct scores (excluding the data obtained from the left ear of the TD group). No statistically significant difference emerged

between these two groups for all subtests; RE GIN (Ath): $U=951$, $p=.327$ between the ‘no pathology’ (Mdn=5.00) and the ‘pathology’ (Mdn=6.00) groups; LE GIN (Ath): $U=955$, $p=.486$ between the ‘no pathology’ (Mdn=5.00) and the ‘pathology’ (Mdn=5.00) groups; RE GIN (% correct): $U=1008.5$, $p=.555$ between the ‘no pathology’ (Mdn=70.00) and the ‘pathology’ (Mdn=71.00) groups; LE GIN (% correct): $U=961$, $p=.369$ between the ‘no pathology’ (Mdn=75.00) and the ‘pathology’ (Mdn=70.00) groups⁵⁶

5.3.6 Sub-tests assessing language processing: Maltese and English nonword repetition tests in quiet

5.3.6.1 *The effect of age on the Maltese and English NWRT(qu)*

⁵⁶ The parametric equivalent was in agreement:

RE Ath; ‘no pathology’ (M= 5.30, SD =2.10) and ‘pathology’ (M= 6.05, SD=2.10): $t(21.8)=-.997$, $p=.339$.

LE Ath; ‘no pathology’ (M= 5.10, SD =1.82) and ‘pathology’ (M= 6.40, SD=3.47): $t(20.9)=-1.635$, $p=.117$.

RE % correct: ‘no pathology’ (M= 67.64, SD =10.87) and ‘pathology’ (M= 71.45, SD=11.86): $t(128)=-.237$, $p=.813$.

LE % correct: Maltese (M= 67.64, SD =10.87) and English (M= 71.45, SD=11.86): $t(128)=1.201$, $p=.169$.

When the scores of the NWRT(qu) were grouped by age, it emerged that the 7-year-old age group obtained a slightly higher percentage error median score than the other two groups for both Maltese and English NWRTs. However, this difference between groups was found to be minimal (less than 1% error) and a large amount of overlap between scores was evident (as shown in figure 80).

Boxplot

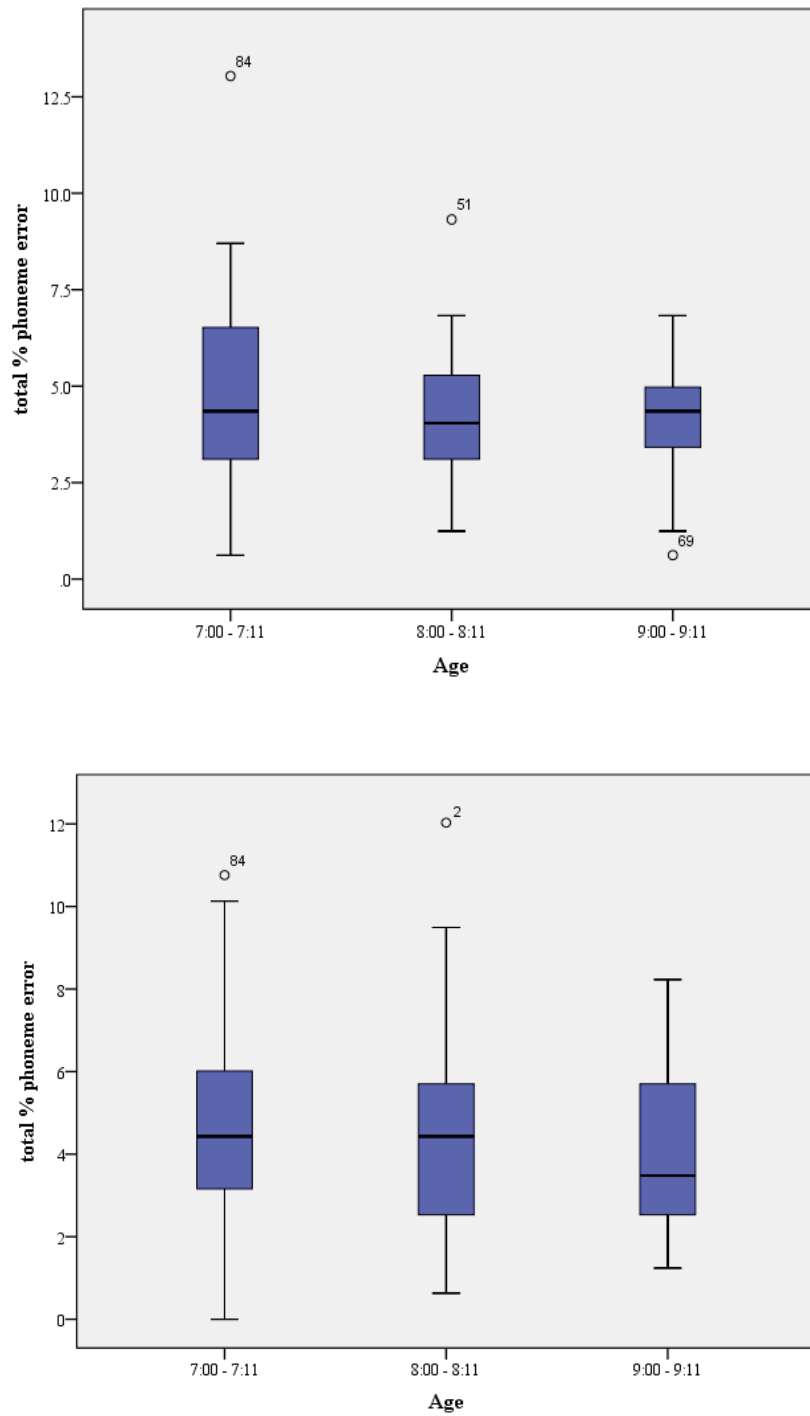


Figure 80 Graphical illustration of the median NWRT(qu) % error scores categorised by 'age group' for the Maltese (above) and English (below) subtests

The tests of normality (appendix C table 80) demonstrate data of a normal distribution for the mNWRT(qu), while the data obtained from the eNWRT(qu) were non-normally distributed. Following normalisation of this data the eNWRT(qu) resulted in a normal distribution.

An ANOVA was run using original data obtained from the mNWRT(qu) and the normalised data from the eNWRT(qu) to compare the effect of age on the percentage error scores. The result showed no statistically significant difference between groups for both subtests mNWRT(qu): [F(2,96) = 2.126, p = .125]; eNWRT(qu): [F(2,95) = 1.528, p = .222].

5.3.6.2 *The effect of gender on the Maltese and English NWRT(qu)*

The male and female participants obtained similar median percentage error scores in both subtests (with less than 1% difference between each group) as shown in figure 81 and through the descriptive statistics in appendix C table 81.

Boxplot

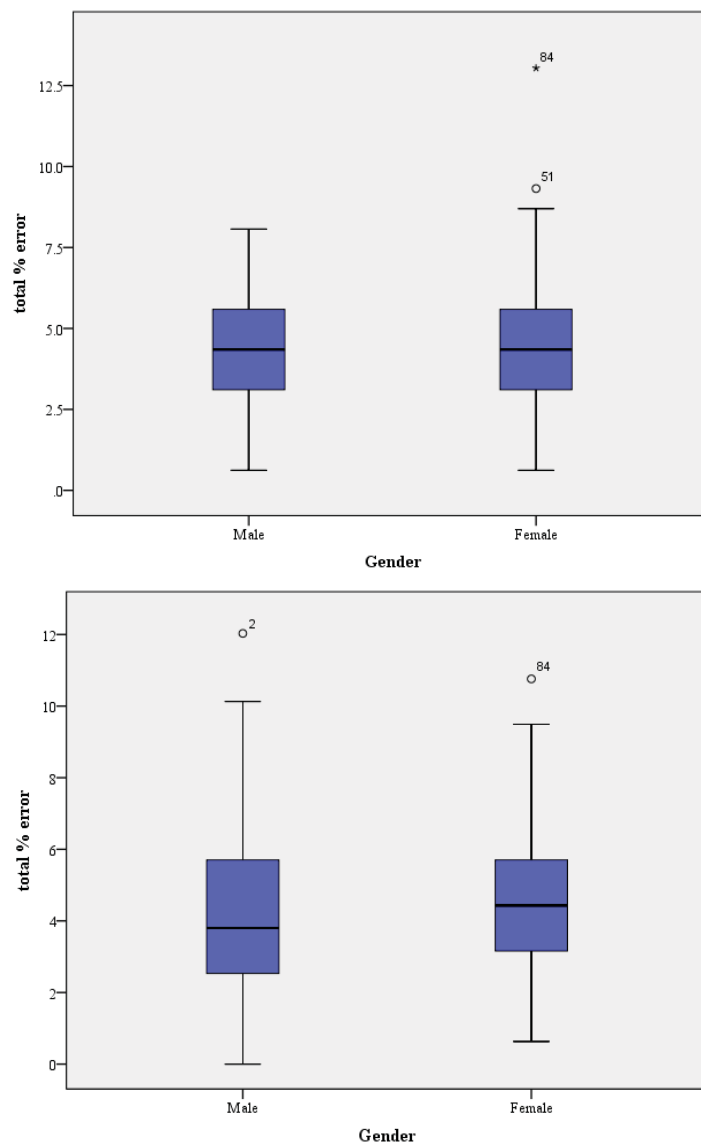


Figure 81 Graphical illustration of the median NWRT(qu) % error scores categorised by 'gender' for the Maltese (above) and English (below) subtests

The tests of normality (appendix C table 82) indicate a combination of normal and non-normal distribution of the data. The M-W test did not expose a statistically significant difference for both subtests of NWRT, (mNWRT(qu): $U=1042.5$, $p=.295$ between the 'male' (Mdn=4.35) and the 'female' (Mdn=4.35) groups; eNWRT(qu): $U=1078$, $p=.513$ between the 'male' (Mdn=3.80) and the 'female' (Mdn=4.43) groups)⁵⁷.

⁵⁷ The parametric equivalent brought out the same result (mNWRT(qu): male ($M= 4.05$, $SD =1.806$) and female ($M= 4.62$, $SD=2.129$): $t(97)=-1.378$, $p=.171$; eNWRT(qu): male ($M = 4.34$, $SD = 2.515$) and female ($M = 4.49$, $SD = 2.173$): $t(96)= -.313$, $p=.755$

5.3.6.3 *The effect of geographic region on the Maltese and English*

NWRT(qu)

Similarly to the previous results, the participants from the two regions of Malta obtained similar scores, with the children living in the South obtaining slightly lower median scores in both subtests (as shown in figure 82).

Boxplot

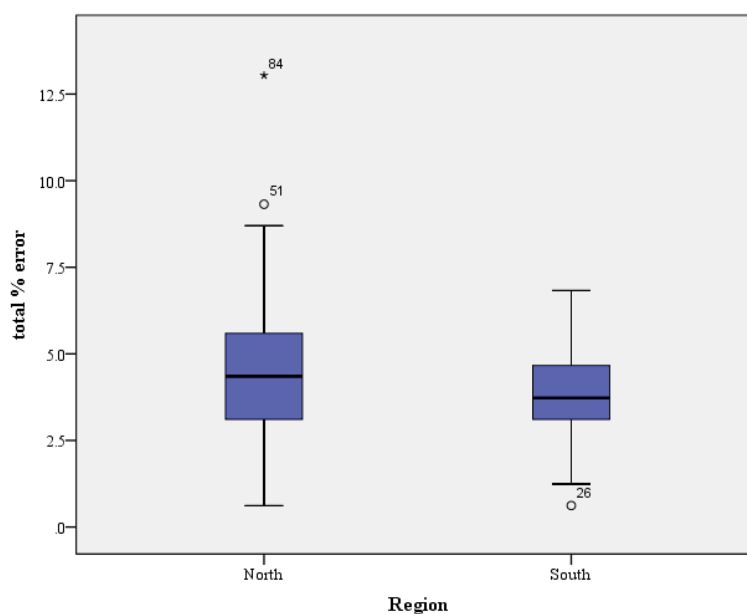


Figure 82 Graphical illustration of the median NWRT(qu) % error scores categorised by ‘geographic region’

The tests of normality (appendix C table 84) indicate a combination of normal and non-normal distribution of the data. The Mann-Whitney test did not reveal a statistically significant difference for both subtests of NWRT, (mNWRT(qu): $U=683.0$, $p=.075$ between

the 'North' (Mdn=4.35) and the 'South' (Mdn=3.73) groups; eNWRT(qu): $U=841.0$, $p=.696$
between the 'North' (Mdn=3.80) and the 'South' (Mdn=4.12) groups)⁵⁸

5.3.6.4 The effect of school type on the Maltese and English NWRT(qu)

The participants attending a church school obtained the best median scores on both Maltese and English-based subtests (figure 82). However, the descriptive results showed that the difference between groups was not greater than 1.5% (refer to appendix C table 85).

⁵⁸ The parametric equivalent brought out the same result (mNWRT(qu): North (M= 4.57, SD =2.113) and South (M= 3.78, SD=1.542): $t(97)=1.685$, $p=.095$; eNWRT(qu): North (M = 4.54, SD = 2.545) and South (M = 4.06, SD = 1.799): $t(96)= .881$, $p=.380$

Boxplot

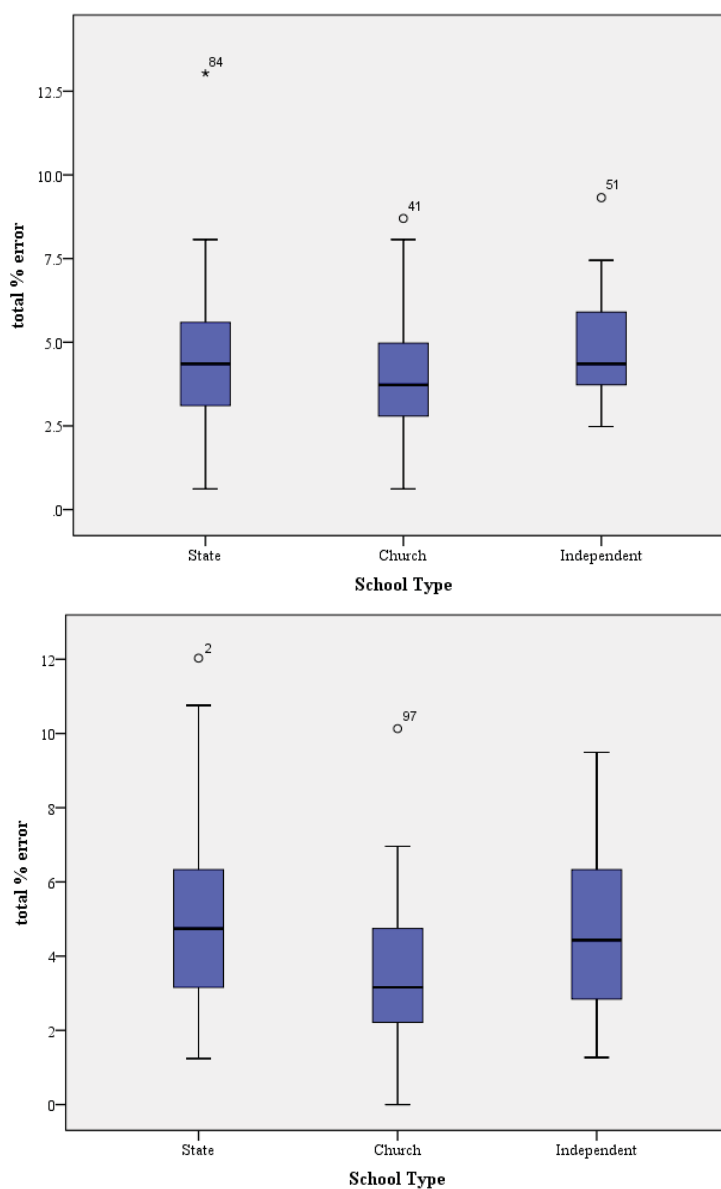


Figure 83 Graphical illustration of the median NWRT(qu) % error scores categorised by 'school type' for the Maltese (above) and English (below) subtests

The K-S suggested all data were of a normal data distribution, while the S-W test of normality resulted in a combination of both normal and non-normal distribution.

Following normalisation of the data the eNWRT(qu) resulted in a normal distribution but the

results from the mNWRT(qu) still varied (refer to appendix C table 86). Considering the relatively small number of participants in each group the Kruskal-Wallis was run to investigate the effect of ‘school type’ on the Maltese and English NWRT(qu). While no statistically significant difference emerged in the mNWRT(qu) ($H(2) = 4.586, p = .101$), a statistically significant difference was observed in the eNWRT(qu) ($H(2) = 7.200, p = .027$)⁵⁹.

5.3.6.5 The effect of primary language on the Maltese and English NWRT(qu)

The median scores of the participants divided in terms of primary language revealed that the children who spoke Maltese as their primary language performed slightly

⁵⁹ The parametric equivalent (ANOVA) was in agreement: mNWRT(qu): $F(2,96) = 2.126, p = .125$
 eNWRT(qu): $F(2,95) = 4.044, p = .021$

Post-Hoc comparisons using the Tukey HSD test indicated that the mean score of the ‘state school’ group ($M=5.06, SD=2.421$) differed significantly from the ‘church school’ group ($M=3.60, SD=1.988$) in the eNWRT(qu).

better in the Maltese subtest and slightly worse in the English subtest than those children who spoke English (figure 84). However, this difference was of less than 1% (as explained in appendix C table 87).

Boxplot

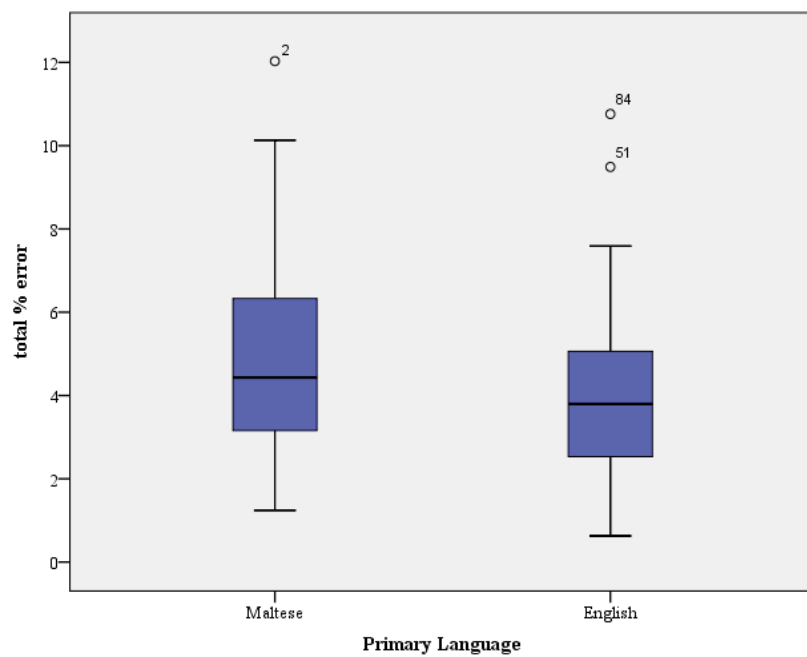
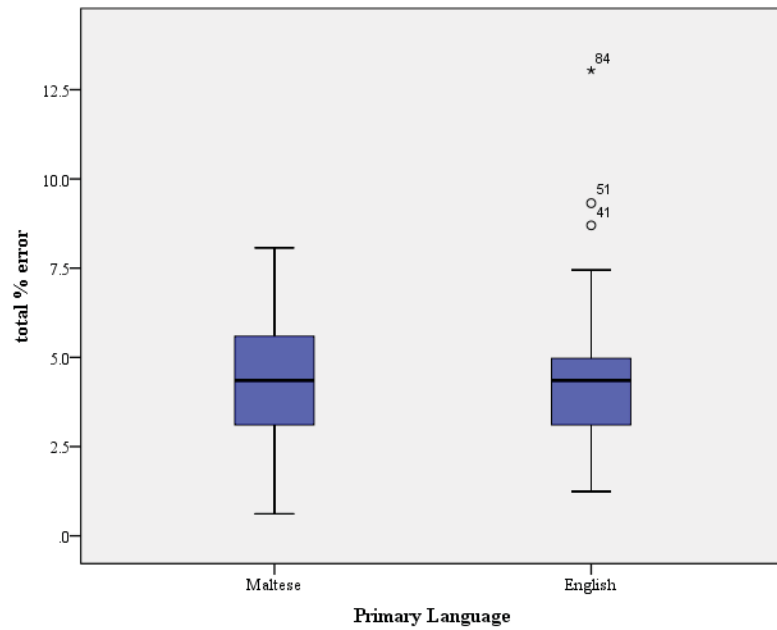


Figure 84 Graphical illustration of the median NWRT(qu) % error scores categorised by 'primary language' for the Maltese (above) and English (below) subtests

Tests of normality indicated primarily data of non-normal distribution, even following attempts at data normalisation (refer to appendix C table 88). The M-W test did not reveal a statistically significant difference for both subtests of NWRT, (mNWRT(qu): $U=1124.0$, $p=.642$ between the 'Maltese' (Mdn=4.35) and the 'English' (Mdn=4.35) primary language groups; eNWRT(qu): $U=1015$, $p=.267$ between the 'Maltese' (Mdn=4.43) and the 'English' (Mdn=3.80) primary language groups)⁶⁰.

⁶⁰ The parametric equivalent was in agreement (mNWRT(qu): Maltese (M= 4.36, SD =1.74) and English (M= 4.41, SD=2.36): $t(97)=-.148$, $p=.882$; eNWRT(qu): Maltese (M = 4.63, SD = 2.50) and English (M = 4.14, SD = 2.18): $t(96)= 1.042$, $p=.300$

5.3.6.6 *The effect of pathology on the Maltese and English NWRT(qu)*

In both subtests the clinical group performed worse than the TD group (figure 85).

The median scores of these two groups varied by between 3 and 4% (as explained through the descriptive statistics in appendix C table 89).

Boxplot

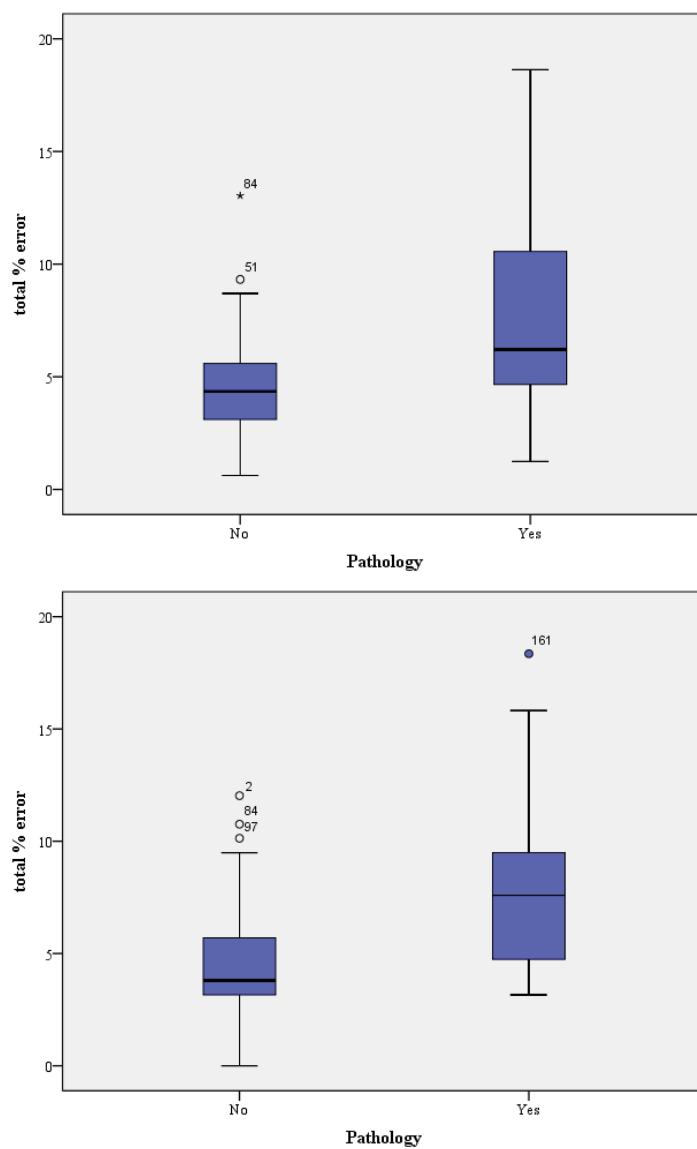


Figure 85 Graphical illustration of the median NWRT(qu) % error scores categorised by ‘pathology’ for the Maltese (above) and English (below) subtests

The tests of normality (appendix C table 90) indicated data of non-normal distribution. The M-W test revealed a statistically significant difference between groups for both subtests of NWRT, (mNWRT(qu): $U=591.0$, $p = <.001$ between the ‘no’ (Mdn=4.35) and the ‘yes’ (Mdn=6.21) pathology groups; eNWRT(qu): $U=443.0$, $p=<.001$ between the ‘no’ (Mdn=3.80) and the ‘yes’ (Mdn=7.59) pathology groups)⁶¹

5.3.6.7 Comparison between the Maltese and English NWRT tests in quiet

When the effects of the independent variables on the Maltese and English NWRT(qu) were investigated, it emerged that the TD participants performed similarly on both subtests. On comparison with the clinical group, a statistically significant difference was evident in which the latter group performed worse. This section highlights the performance of the TD participants as well as the clinical group on these two subtests. Figure 86 displays the median percentage error scores of the TD participants on the two subtests. Unlike the NWRT(n) (section 5.3.2.7), the TD group obtained similar percentage error scores on these two tests despite the different linguistic base of the nonwords (as demonstrated in figure 86)

⁶¹ The parametric equivalent was in agreement (mNWRT(qu): ‘no’ (M= 4.38, SD =2.011) and ‘yes’ (M= 7.80, SD=4.86) pathology groups: $t(23.76)= -3.322$, $p=.003$; eNWRT(qu): ‘no’ (M= 4.42, SD =2.31) and ‘yes’ (M= 8.28, SD=4.09) pathology groups: $t(26.57)= -4.644$, $p=<.001$

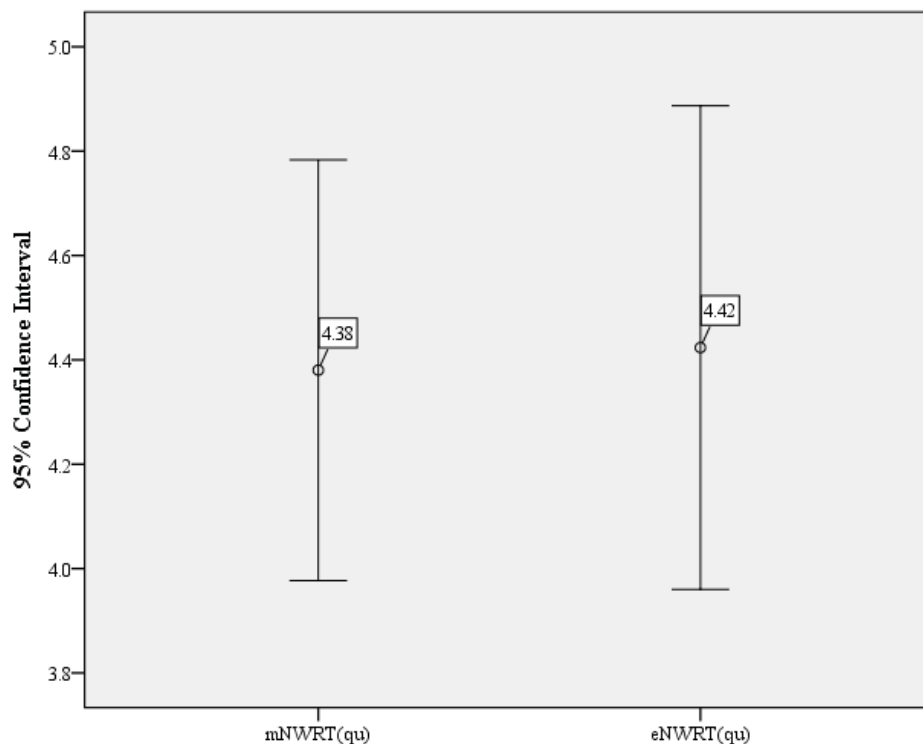


Figure 86 Graphical illustration of the median % error scores of the Maltese and English NWRT in noise (TD subjects)

The Wilcoxon signed ranks test demonstrated no statistically significant difference between the performance of the participants on the two tests, mNWRT(qu) (Mdn = 4.35) and the eNWRT(qu) (Mdn = 3.80), $z = -0.558$, $p = .577$ ⁶²

The same plot was constructed for the children forming the clinical group. These children were also found to exhibit a similar mean percentage error in the two subtests, as is illustrated in figure 87.

⁶² The parametric equivalent (paired samples t-test) test was in agreement –

mNWRT(qu) (mean = 4.38, SD = 2.01) and eNWRT(qu) (mean = 4.42, SD = 2.31), $t(97) = -0.209$, $p = .835$

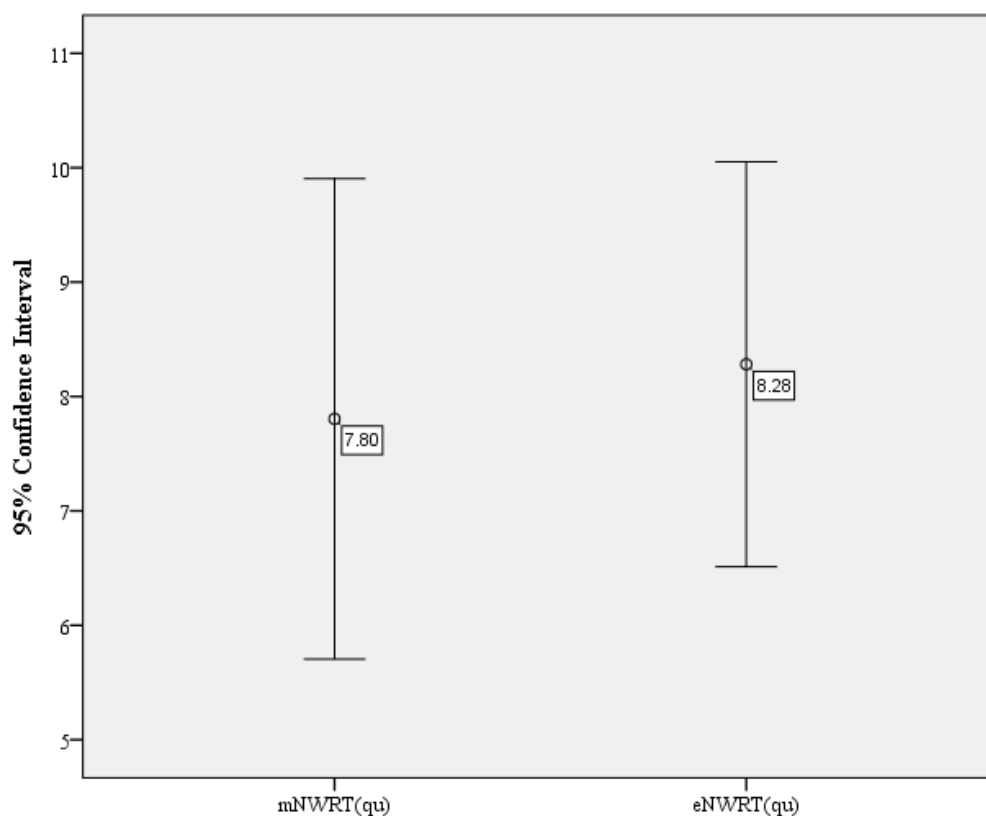


Figure 87 Graphical illustration of the mean % error scores of the Maltese and English NWRT in quiet (clinical group)

The Wilcoxon signed ranks test resulted in no statistically significant difference in performance between the two subtests (mNWRT(qu): Mdn = 6.21; eNWRT(qu): Mdn = 7.59) in this group: $z = -1.095$, $p = .274$ ⁶³.

⁶³ The parametric equivalent (paired samples t-test) test was in agreement –

mNWRT(qu) (mean = 7.80, SD = 4.86) and eNWRT(qu) (mean = 8.28, SD = 4.09), $t(22) = -0.772$, $p = .448$

5.3.7 Sub-tests assessing language processing: Sentence Imitation Task

5.3.7.1 *The effect of age group on the SIT*

The median scores obtained from the participants demonstrated an improvement in scores with increasing age (figure 88).

Boxplot

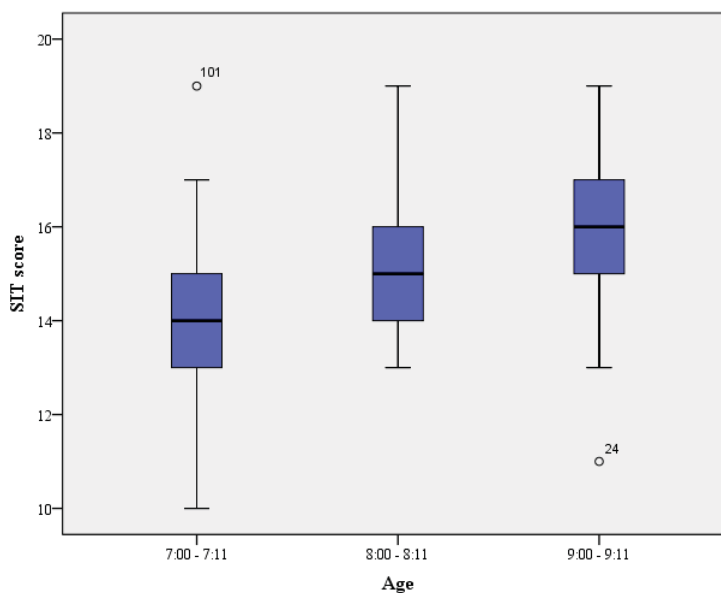


Figure 88 Graphical illustration of the median SIT scores categorised by ‘age group’

The tests of normality suggest data of normal distribution across all age groups (refer to appendix C table 92). Therefore the ANOVA was run to investigate the effects of ‘age’ on the scores obtained in the SIT. A statistically significant difference was found between the performance of each group [$F(2,98) = 7.019, p = .001$]. Post-Hoc comparisons using the Tukey HSD test indicated that the mean score of the ‘7;00 – 7;11 year old’ group ($M=14.30, SD=1.85$) differed significantly from the ‘8;00 – 8;11 year old’ group ($M=15.33, SD=1.43$) and from the 9,00 – 9;11 group ($M=15.84, SD=1.80$). The ‘8;00-8;11 year old’ group did not differ significantly from the ‘9;00 – 9;11 year old’ groups.

5.3.7.2 *The effect of gender on the SIT*

Both male and female participants were found to perform similarly with less than 0.25 difference between their median/mean scores (as shown in figure 89 and explained numerically through the descriptive statistics in appendix C table 93).

Boxplot

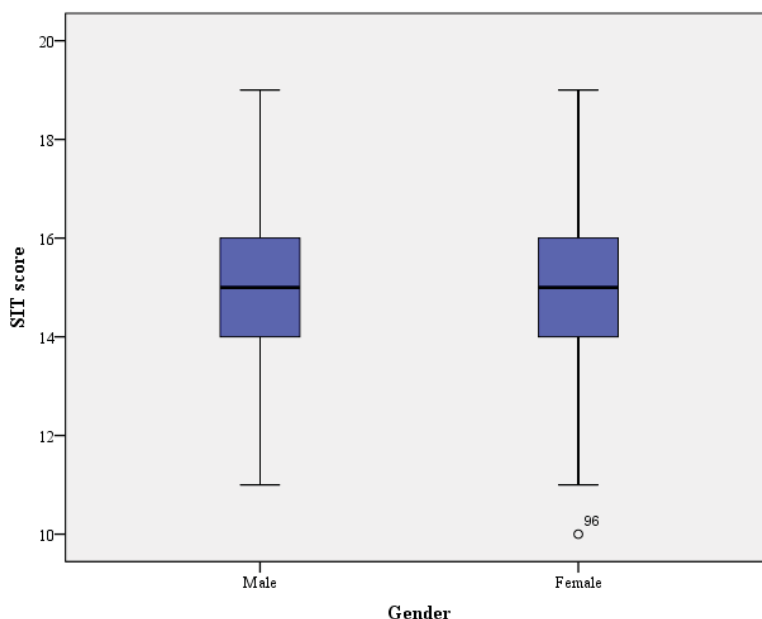


Figure 89 Graphical illustration of the median SIT scores categorised by ‘gender’

The tests of normality indicated data of a normal distribution in the male participants but not in the female participants (appendix C table 94). The M-W test was used to examine the effect of ‘gender’ on the performance of the SIT score. No statistically significant difference emerged between the ‘male’ (Mdn = 15.00) and the ‘female’ (Mdn = 15.0) groups: $U = 1225.5$, $p = .925$ ⁶⁴.

5.3.7.3 *The effect of geographic region in the SIT*

The participants who live in the South region of the island were found to score slightly lower (less than 1 point) on average than those who live in the North. Greater variability in the scores also emerged in the ‘South’ group (as illustrated in figure 90 and appendix C table 95).

Boxplot

⁶⁴ The parametric equivalent was in agreement: SIT ‘male’ (M= 15.24, SD =1.89) and ‘female’ (M= 15.10, SD=1.74) groups: $t(99) = 0.375$, $p = .708$;

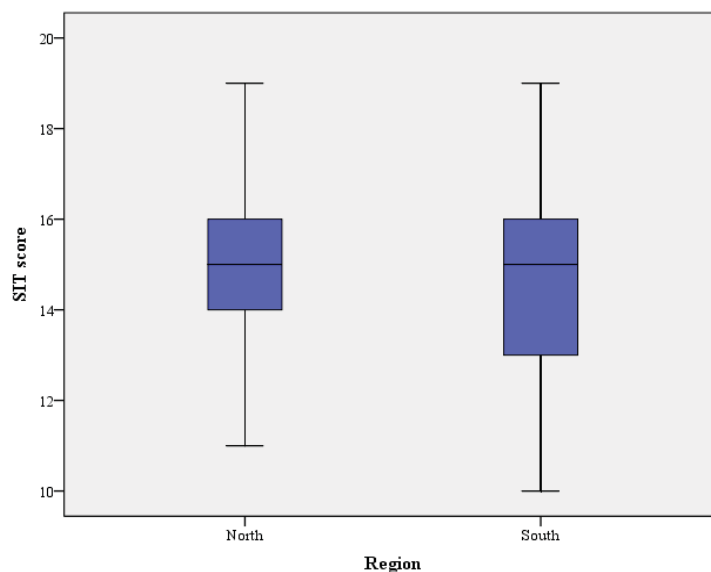


Figure 90 Graphical illustration of the median SIT scores categorised by ‘geographic region’

The tests of normality indicated data of a normal distribution in the ‘South’ group but not in the ‘North’ group (appendix C table 96). The M-W test was used to examine the effect of ‘region’ on the SIT score. No statistically significant difference emerged between the ‘North’ (Mdn = 15.00) and the ‘South’ (Mdn = 15.0) groups: $U = 828.5$, $p = .439$ ⁶⁵.

5.3.7.4 The effect of school type on the SIT

When categorised in terms of school type it emerged that the participants who attended a state school obtained the highest median scores, and those who attended a church school scored lowest on average (figure 91).

Boxplot

⁶⁵ The parametric equivalent was in agreement: SIT ‘North’ ($M = 15.25$, $SD = 1.70$) and ‘South’ ($M = 14.88$, $SD = 2.10$) groups: $t(99) = 0.886$, $p = .378$;

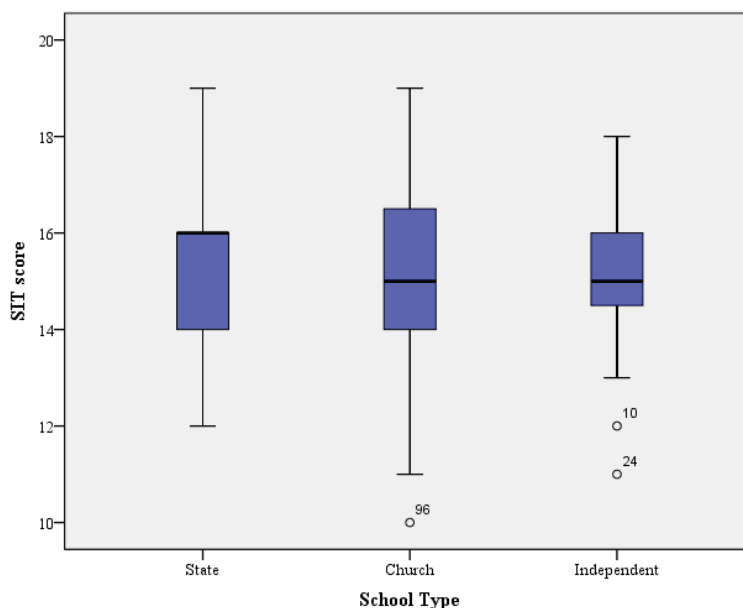


Figure 91 Graphical illustration of the median SIT scores categorised by ‘school type’

The tests of normality revealed data of a normal distribution across all groups (appendix C table 98). An ANOVA was run to investigate the effect of ‘school type’ on the performance in the SIT. No statistically significant difference emerged between these three groups: $F(2,98) = 1.001$, $p = .371$.

5.3.7.5 *The effect of primary language on the SIT*

With the SIT administered in the participants’ primary language, those who used English as a PL obtained a score that was marginally higher than the group who used Maltese. The boxplot in this figure further highlights the similarity in the performance of these two groups.

Boxplot

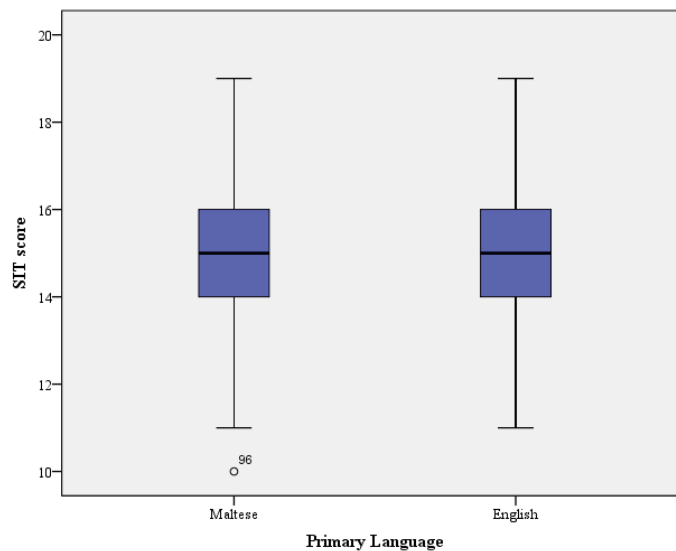


Figure 92 Graphical illustration of the median SIT scores categorised by ‘primary language’

The tests of normality (appendix C table 99) indicated data of normal distribution in all groups. The independent samples t-test did not expose a statistically significant difference between the ‘Maltese’ (M = 15.12, SD = 1.139) and the ‘English’ (M = 15.21, SD = 1.586) primary language groups: $t(99) = -0.263$, $p = 0.793$.

5.3.7.6 *The effect of pathology on the SIT*

The participants forming the clinical group obtained a lower mean score by 2 points when compared with the TD participants (refer to the respective descriptive statistics in appendix C table 101).

Boxplot

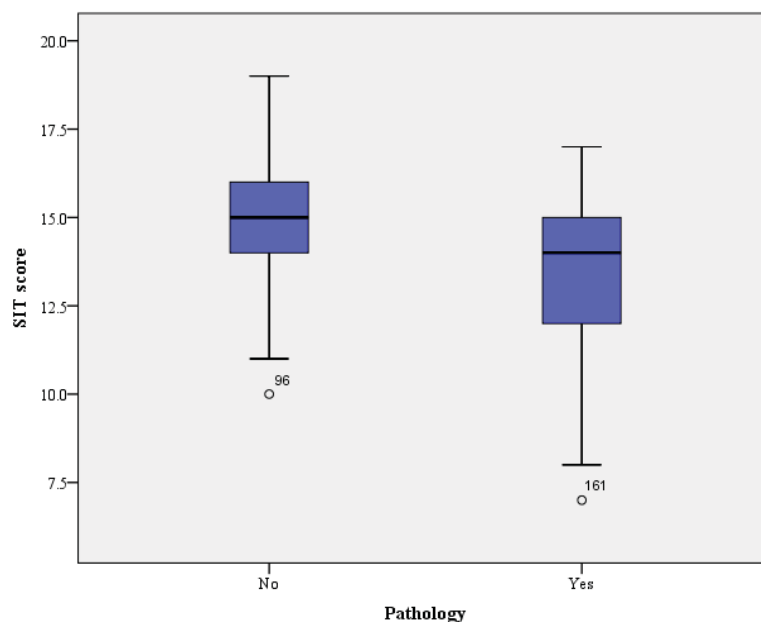


Figure 93 Graphical illustration of the median SIT scores categorised by 'pathology'

The tests of normality revealed data of non-normal distribution from the TD participants and normally distributed data from the clinical group (appendix C table 102). The M-W test showed that the difference in scores between the TD (Mdn = 15.00) and the clinical (Mdn = 14.00) groups was statistically significant: $U = 762.5$, $p = <0.001$ ⁶⁶

5.4 Summary of results

The previous section detailed the descriptive and inferential statistics related to the performance of the TD sample divided into the categorical variables, as well as the TD and clinical samples. The reader is provided with a summary of these results highlighting the outcomes. It is worth mentioning here that the comparisons made in this chapter did not include corrections and this might increase the likeliness that some significant correlations emerged by chance:

⁶⁶ The parametric equivalent was in agreement: SIT 'no' ($M = 15.16$, $SD = 1.79$) and 'yes' ($M = 13.14$, $SD = 2.45$) groups: $t(36.8) = 4.099$, $p = <0.001$;

- In the QCAP, there were no statistically significant differences in the performance of the TD group when divided into their demographic factors.
- Overall, there were no statistically significant differences in the performance of the TD group when divided into their demographic factors in the APD assessment battery, with a few exceptions –
 - In the DDFR a significant age effect emerged in the right ear, where the youngest age group (7;00 to 7;11 years) performed worse than the older age groups. An effect of geographic region also emerged on the right side for DDFR, in which the children living in the Northern part performed significantly better. Finally, an effect of primary language was found in the DDFR bilaterally and the DDFA on the right side. In all these cases the PL English participants performed significantly better than the PL Maltese group.
 - In the DPT there was a significant effect of school type on the left ear scores, where the mean score of the ‘independent school’ group was significantly better than the ‘state school’ group.
 - There was an ‘age’ effect on the performance in the right ear GIN percentage correct score, in which the mean score of the ‘7;00 – 7;11 year old’ group differed significantly from the ‘9;00 – 9;11 year old’ group. The ‘8;00-8;11 year old’ group also differed significantly from the ‘9;00 – 9;11 year old’ group. Within this test ‘language effects’ also emerged in the left ear performance of the GIN percentage correct score, where the PL English group performed significantly better than the PL Maltese group.
- In the DD tasks, a significant REA emerged in both the TD and clinical groups.
- The TD participants performed significantly better in the mNWRT(n) in comparison with the eNWRT(n)

- There was no significant difference in the performance of the clinical group on the two NWRT(n).
- Overall there were statistically significant differences in the performance of the TD and clinical groups, with some exceptions where no difference in performance emerged, namely:
 - eNWRT(n)
 - FPT (both ears)
 - GIN (both ears) when scored in terms of *Ath* and *percentage correct*
- In the tests of language processing there were overall no statistically significant differences within the TD group across demographic factors, with the exception of a school effect in the eNWRT(qu): the ‘church school’ group performed significantly better than the ‘state school’ group.
- There was a statistically significant difference in the performance of the TD and clinical groups in all tests of language processing.
- Both groups exhibited no significant difference in the percentage error scores of the Maltese and English NWRT(qu).

5.5 Related studies emerging from this research

Throughout this study, the effects of the independent variables: (1) age, (2) gender, (3) region, (4) school type, and (5) primary language on an assessment battery of auditory processing skills was investigated. Later in the study, the impact of socio-economic status on these skills also became of interest. A sample of 41 participants accepted to take part in this further study. The reader is referred to Tabone, Said, Grech and Bamiou (2017) (appendix C - 6) for details related to this study.

Within this study, the performance of TD children was also compared with a small group of children diagnosed with a neurodevelopmental disorder and reported by their carers to exhibit listening difficulties. This was later further explored, with the TD performance compared with specific clinical groups. The results of which are presented in Tabone et al. (2016) (appendix C – 7).

5.5.1 The impact of socioeconomic status on auditory processing skills in Maltese children. The SES of the 41 children, defined on the basis of maternal education, was obtained and categorised into one of four SES categories: (1) high-mid; (2) mid; (3) low-mid; (4) low. Figure 94 illustrates the distribution.

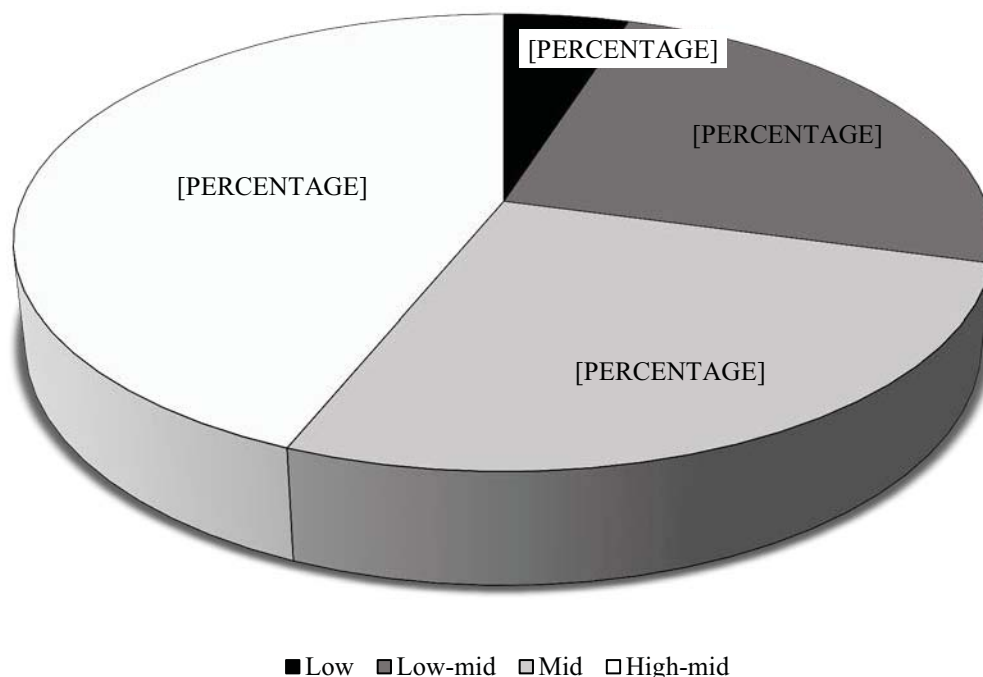


Figure 94 SES group distribution

The mean scores for each of the AP subtests are displayed in table 65. The Kruskal-Wallis test was used to examine whether the observed difference between SES groups was statistically significant for the participants in this study. In all tests of temporal processing, the two higher SES groups obtained better scores than the two lower SES groups, with statistically significant differences evident in the DPT for both right ($p = .027$) and left ($p = .017$) ears. The Spearman's correlation test revealed a moderate positive correlation between SES and the DPT which was statistically significant (table 66). This shows that the higher the SES, the better the subjects' performance on the DPT. The mean scores for the DDFR in the right ear were marginally higher in the 'mid' group than the rest of the groups while the highest score in the left ear was achieved by the 'high-mid' group. This was not the case for the DDFA, where mean scores revealed a more or less similar performance in both ears across all groups. The same can be said for the eNWRT(n), where all groups obtained very

similar percentage error scores. The opposite emerged in the mNWRT(n), as the ‘low’ category group had higher percentage error scores than the other groups. These differences were not found to be statistically significant.

Table 65

Mean scores and comparisons between groups on each subtest of auditory processing

Test	SES group	Mean score (right)	SD	<i>p</i> -value	Mean score (left)	SD	<i>p</i> -value
DDFR (% correct)	low	91.25	1.77	.639	87.50	7.07	.213
	low-mid	92.22	9.85		88.33	10.82	
	mid	95.00	6.02		90.23	6.84	
	high-mid	94.31	6.23		91.94	5.52	

DDFA (% correct)	low	97.22	3.93	.801	94.44	3.93	.683
	low-mid	97.53	4.03		88.36	4.03	
	mid	91.00	11.78		93.95	7.12	
	high-mid	95.06	7.35		91.65	7.90	
GIN (smallest gap detection (Ath)/ms)	low	--*		.491	--		.380
	low-mid	6.60	4.85		5.60	3.67	
	mid	5.29	0.91		4.00	1.53	
	high-mid	5.40	2.38		4.93	2.46	
GIN (% correct)	low	--		.383	--		.380
	low-mid	63.60	18.04		65.40	24.92	
	mid	69.62	13.49		76.24	14.25	
	high-mid	71.80	13.48		77.04	13.46	
DPT (% correct)	low	50.00	28.28	.027	56.67	14.14	.017
	low-mid	50.67	23.40		47.33	21.78	
	mid	67.88	21.25		76.97	23.16	
	high-mid	78.15	17.68		75.18	19.78	
FPT (% correct)	low	54.87	14.14	.078	56.67	18.86	.079
	low-mid	79.34	21.27		75.33	27.07	
	mid	90.30	13.45		93.33	21.25	
	high-mid	90.56	14.47		92.96	17.68	
NWRtn (% error)		English			Maltese		
	low	10.94	0.44	.749	12.26	4.56	.414
	low-mid	11.04	2.75		9.97	1.58	
	mid	10.62	3.31		9.03	2.97	
	high-mid	11.10	4.76		9.82	4.63	

*From the small number of subjects that formed the low SES group, no results were obtained on the GIN.

Table 66

Correlation between SES and the DPT

		SES	DPT (right)	DPT (left)
Spearman's Rho	SES	1.000	.452**	.374**
	Correlation coefficient			
	Sig. (2-tailed)		.003	.016
	N	41	41	41

** . Correlation is significant at the 0.01 level (2-tailed).

In addition to the effect of SES on the APD subtests, Said (2016) investigated the effect of SES on the subtests of language processing used in this research, using the same

participants. Results revealed no statistically significant differences across SES in all subtests: eNWRT(qu) ($p = .319$); mNWRT(qu) ($p = .705$); SIT ($p = .284$)

5.5.2 A comparative study on the auditory and language processing skills in Maltese children. All the data from the TD participants as well as the ones diagnosed with literacy difficulties (LD) ($n = 12$) in this study, were combined with data obtained from children with a LI ($n = 11$) (Azzopardi, 2015) and ADHD ($n = 30$) (Tabone, 2015) on the same subtests used in this research in order to bring out further comparative results. The results of this study have been found to substantiate those reported in this research.

Parental report scores of the TD group were on average lower than all the clinical groups, indicating less difficulties with listening skills. Statistically significant differences ($p < .001$) were evident between the TD group and each of the clinical groups, in which the clinical groups obtained poorer scores. No significant differences between clinical groups emerged, suggesting that similar listening difficulties are reported from parents of children in the different clinical groups.

Tabone et al. (2016) report significant correlations between the total QCAP score and all auditory processing subtests using linguistic stimuli. The stronger correlations were found with the DD tests: DDFR on the right ($r = -.42$, $p < .001$) and left ($r = -.45$, $p < .001$) and the DDFA in both ears (right: $r = -.40$, $p < .001$; left: $r = -.41$, $p < .001$). Weaker but significant correlations were found with both Maltese-based ($r = .24$, $p = .003$) and English-based ($r = .18$, $p = .047$) NWRT(n) tests. As regards to the QCAP correlations with AP subtests of non-linguistic content, significant correlations only emerged in the left ear of two of the subtests: The FPT ($r = -.21$, $p = .01$) and the GIN ($r = -.25$, $p = .002$).

The authors also found a significant difference between groups in all subtests using linguistic stimuli. The TD group performed significantly better than the ADHD and LI groups on all DDTs. When compared with the LD group a significant difference was observed only in the left ear for both DDT subtests, where the TD group performed better. Both LI and LD groups revealed better scores obtained from the right ear when compared with the left. This pattern was not so much observed in the TD and ADHD groups.

Both NWRT(n) subtests revealed significant group differences. The ADHD group was found to perform significantly better than all other groups on the eNWRT(n), and scored similarly to the TD group in the mNWRT(n). The TD group performed significantly better than the LI group on both NWRT subtests and better than the LD group on the mNWRT(n). The LD group obtained lower mean error scores than the LI group. However, these differences were not statistically significant.

Few significant effects emerged between groups in the subtests using non-linguistic stimuli (Tabone et al., 2016). Generally, significant effects were evident only in one ear with the exception of the DPT comparison between the ADHD and LD groups, where the ADHD group performed significantly better than the LD group in both ears. The LD group was found to perform weakest in the DPT.

The LI group was reported to perform the weakest in all tests of language processing. The difference in performance was significant when compared with all TD, ADHD, and LD groups. There was no significant difference between the TD and ADHD groups on the NWRT(qu) subtests, and between the TD and the LD groups on the English NWRT(qu).

5.6 Correlations and regression analysis

A correlation analysis using all the participants in this study was carried out between the subtests to determine the extent with which they agree. In light of the variability in data distribution among subtests (refer to section 5.1.1 *Normality testing of the assessment battery for auditory processing*), the nonparametric analyses (Spearman's rho) are presented below (table 67). The parametric equivalent (Pearson's correlation coefficient) are presented in appendix C - 8, table 103. The variables with a moderate statistically significant correlation (an explanation of correlation strength is provided in Chapter 4, section 4.1: Reliability and validity testing) are highlighted. These results are reported next in terms of: (1) subtests assessing language processing, (2) auditory processing subtests using linguistic content, and (3) auditory processing subtests using non-linguistic content.

Table 67

Spearman's correlations between all subtests

rho	Spearman's Correlation Coefficient	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		1	QCAP Score	1	.160	.217*	.113	.111	-.288**	-.249**	-.170	.177	.119	-.233**	-.297**	-.162	-.226*	.046	.014
2	mNWRT(qu)		1	.562**	.376**	.276**	-.305**	-.189*	-.251**	-.151	-.206*	-.100	-.397**	-.314**	-.160	.000	.097	.138	-.119
3	eNWRT(qu)			1	.362**	.294**	-.379**	-.264**	-.408**	-.239**	-.196*	-.211*	-.387**	-.265**	-.277**	.160	-.099	.365**	-.340**
4	mNWRT(n)				1	.282**	-.287**	-.071	-.249**	-.159	-.180*	-.180*	-.091	-.267**	-.201*	.048	-.098	.067	-.155
5	eNWRT(n)					1	-.108	-.073	-.188*	-.174	-.114	-.132	-.176	-.165	-.060	-.114	.000	.097	-.218*
6	SIT						1	.265**	.266**	.057	.059	.248**	.319**	.402**	.326**	-.001	.090	-.187	.249*
7	DPT (right)							1	.699**	.325**	.332**	.251**	.337**	.187*	.369**	-.216*	.271*	-.323**	.394**
8	DPT (left)								1	.306**	.319**	.192*	.284**	.233**	.397**	-.287**	.350**	-.386**	.422**
9	FPT (right)									1	.779**	.164	.055	.203*	.142	-.112	.256*	-.142	.239*
10	FPT (left)										1	.102	.049	.295**	.209*	-.198	.259*	-.217*	.341**
11	DD(FA) (right)											1	.302**	.347**	.319**	.042	.056	-.136	.281**
12	DD(FA) (left)												1	.026	.350**	.026	-.127	-.025	.064
13	DD(FR) (right)													1	.287**	-.073	.124	-.278**	.304**
14	DD(FR) (left)														1	-.174	.264*	-.227*	.392**
15	GIN Ath (right)															1	-.723**	.552**	-.397**
16	GIN % (right)																1	-.504**	.583**
17	GIN Ath (left)																	1	-.759**

5.6.1 Subtests of language processing. Both NWRT(qu) tests and the SIT demonstrated significant correlations with each other. The mNWRT(qu) with the eNWRT(qu) showed the highest correlations ($R_S=.562$), while both Maltese and English NWRT(qu) correlated moderately with the SIT ($R_S=-.305$ and $R_S=-.379$ respectively). These correlations are illustrated graphically through scatter plots in figure 95.

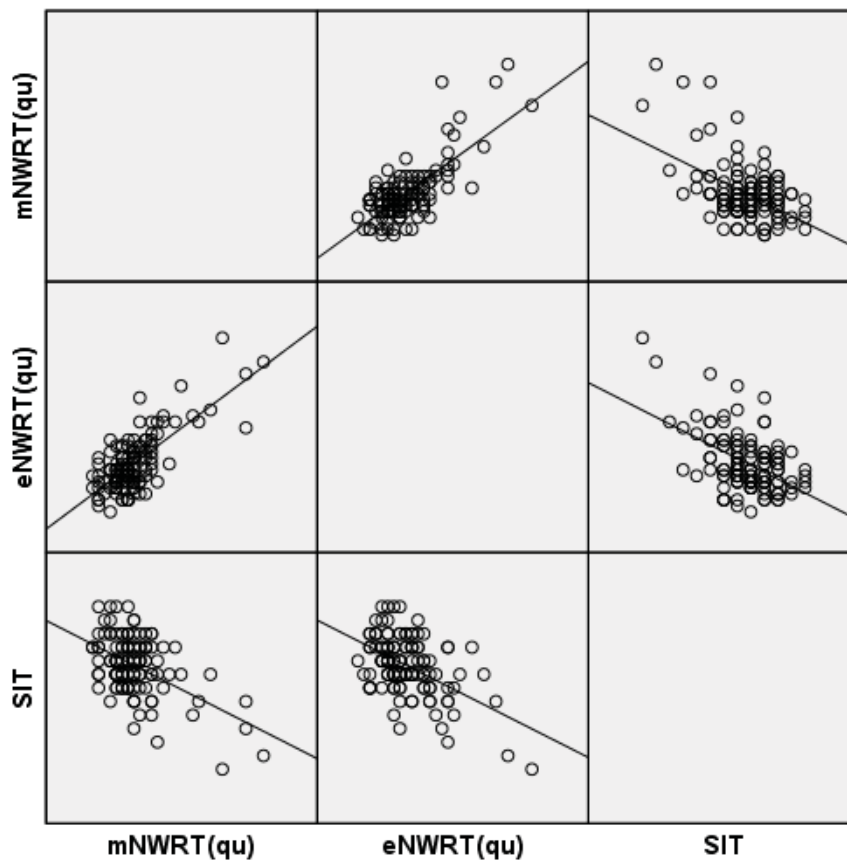


Figure 95 Correlation between the subtests of language processing

5.6.2 Auditory processing subtests using linguistic content. Among these subtests, weak but significant correlations emerged between the Maltese and English NWRT(n) ($R_S=.282$). Significant correlations also emerged between the mNWRT(n) and the DDFR for both right ($R_S=-.267$) and left ($R_S=-.201$) ears. There was no correlation between the eNWRT(n) and the DDFR for both ears and between both NWRT(n) and the DDFA subtests. These results are illustrated in figure 96.

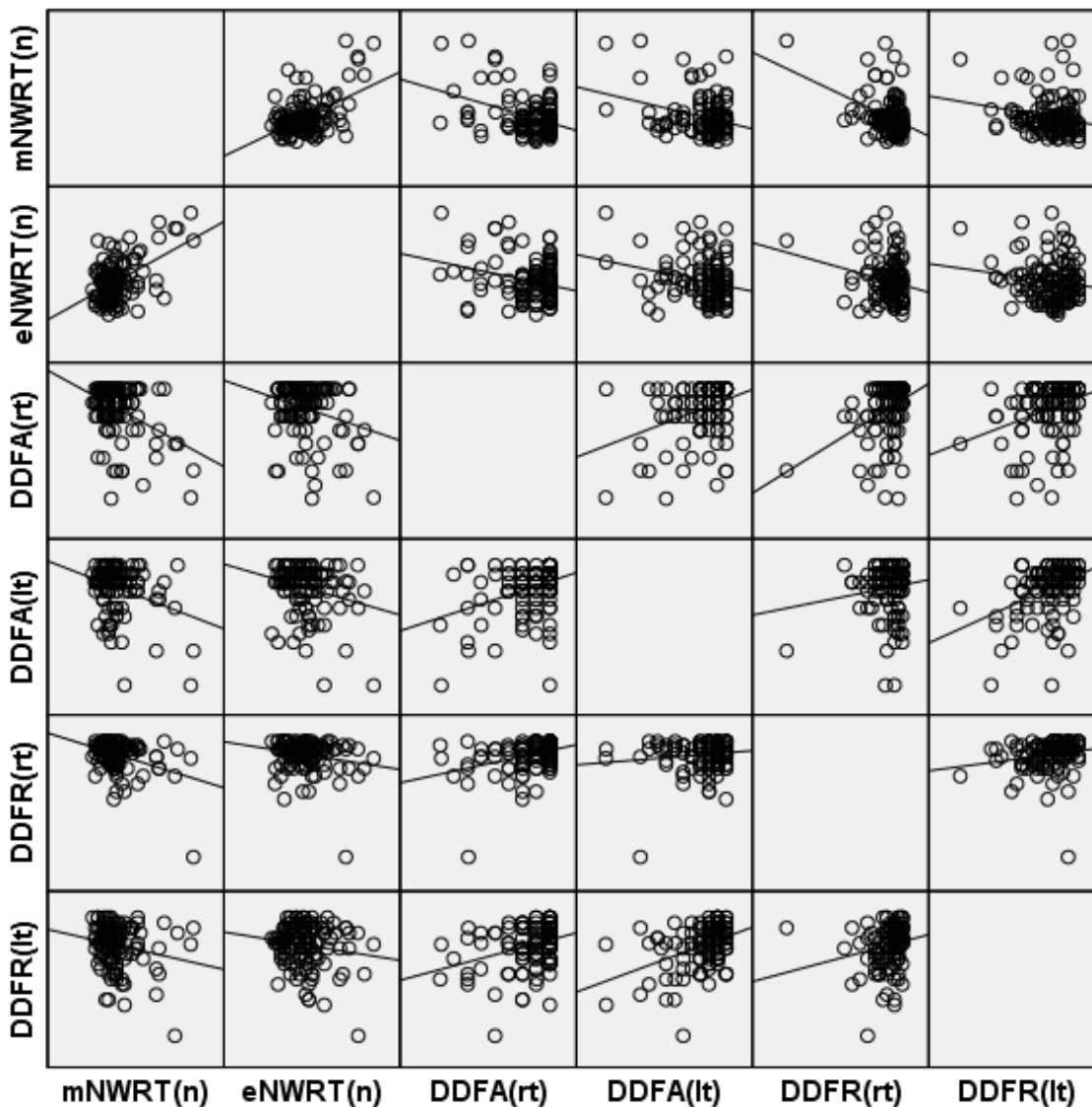


Figure 96 Correlation between the linguistic based subtests of auditory processing

5.6.3 Auditory processing subtests using non-linguistic content. High correlations emerged between the right and left ears of each subtest, namely in the DPT ($R_S=.699$), the FPT ($R_S=.779$) and the GIN for both Ath scoring ($R_S=.552$) and the percentage correct scoring ($R_S=.583$). Strong correlations also emerged between the two scoring methods of the GIN subtest for each ear: right ($R_S= -.723$) and left ($R_S= -.759$). Significant but weaker correlations also emerged across the different subtests, with moderate correlations between the DPT and FPT subtests and weak to moderate correlations between the GIN and both DPT and FPT. Figures 5.78 to 5.80 illustrate these relationships.

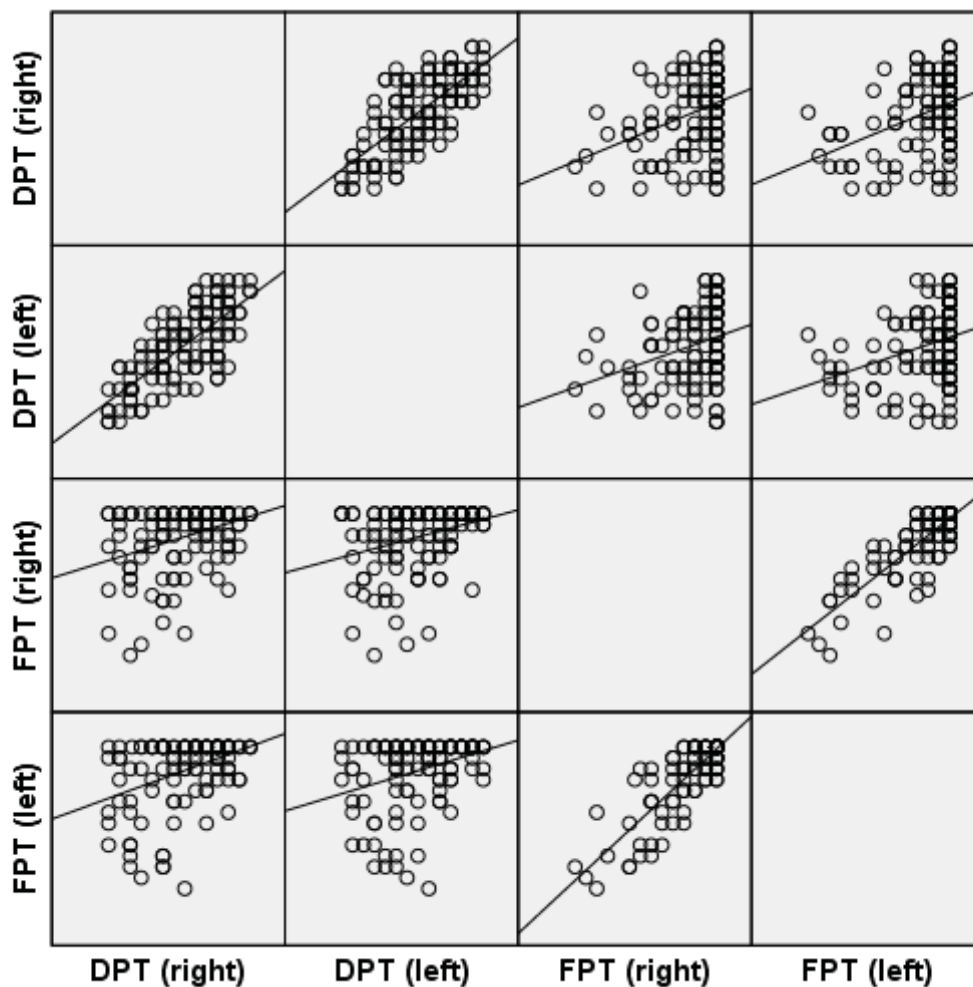


Figure 97 Correlation between the DPT and FPT subtests

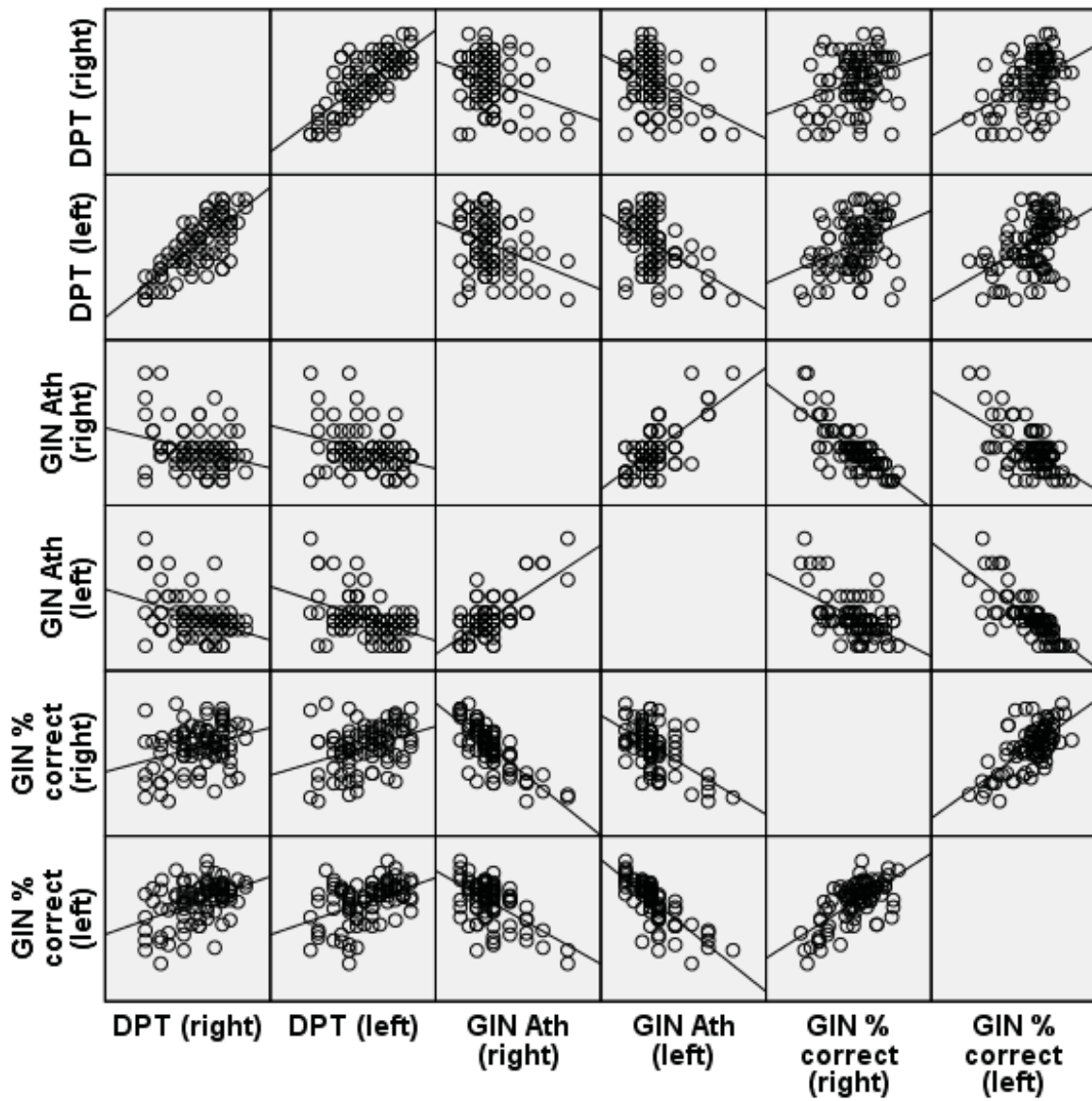


Figure 98 Correlation between the DPT and GIN subtests

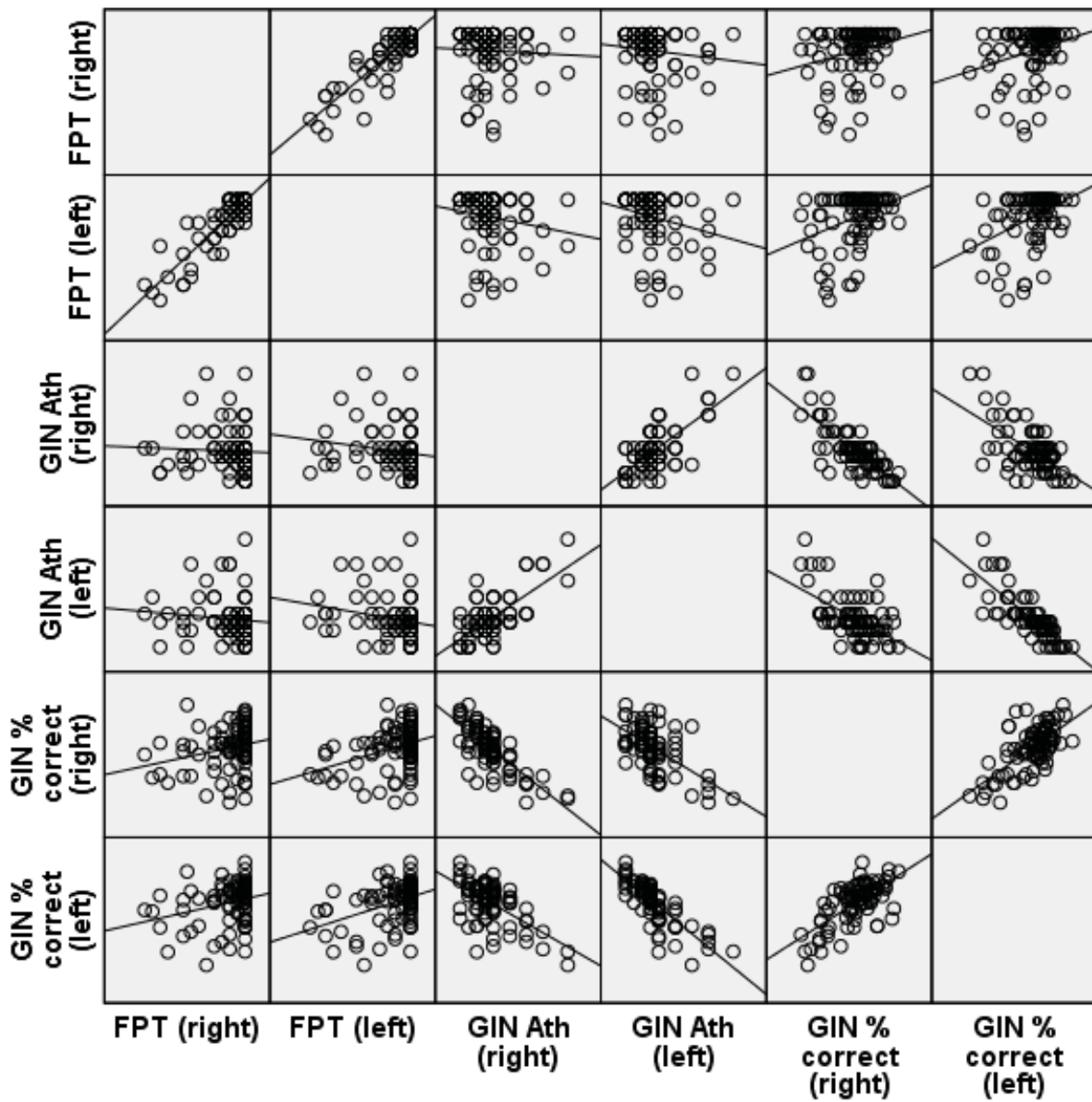


Figure 99 Correlation between the FPT and GIN subtests

5.6.4 Regression analysis. This section highlights the predictors of each subtest used in the assessment battery, both in terms of the independent variables (age, gender, region,

school type, primary language, and pathology) and the subtests themselves (covariates). In order to highlight these findings, the model of choice was that of Generalized Linear Models (GLiMs). The main rationale underlying this choice was the overall non-normally distributed data across the dependent variables obtained in this research. Unlike the linear regression models, GLiMs are flexible in that they can apply regression models to non-normally distributed data (Dunteman & Ho, 2006). The *backward elimination* method adopted for the regression analysis of each dependent variable was explained in section 3.1.4. An example of this procedure is presented in appendix C -9 section 5.7.

Table 68 presents the predictors in terms of the independent variables which emerged when the GLiMs were run first using only the TD participants, and then the entire sample (TD and clinical sample together). This table displays both the ‘test of model effects’ (which highlights the statistically significant predictors when all variables are inputted simultaneously) and the ‘parsimonious model’ (which displays the remaining statistically significant predictors once all the predictors of no significance have been removed, thus accomplishing the desired level of prediction with the least possible predictors (Gray & Pathmanathan, 2016)).

Table 69 displays the predictors of each subtest in terms of the other subtests within the assessment battery. It was of interest to determine whether any of the subtests emerge as significant predictors of other subtests. The significant predictors were highlighted in the table. In subtests where the ears were assessed separately, the significant predictors were only considered and highlighted when the significance emerged in the latter group for both ears.

5.6.4.1 *QCAP and subtests of language processing.* When only the TD children were included in the sample no significant predictors for the QCAP emerged amongst the independent variables, suggesting that all TD children were perceived to have similar

listening skills irrespective of age, gender, geographic region, PL, or school type. When the entire sample was included in the GLiM, ‘pathology’ emerged as the only significant predictor.

‘Pathology’ also emerged as the strongest significant predictor in each of the subtests on language processing in terms of the independent variables (table 68). When only the TD participants were included in the model: (1) ‘Age’ emerged as a predictor of both the SIT and the eNWRT(qu), where the participants obtained improved scores with age, as was illustrated in figures 5.69 and 5.61 respectively. (2) ‘School type’ was the strongest predictor of the eNWRT(qu), in which the participants attending a church school performed best and those attending a state school performed the poorest (figure 83). (3) No significant predictors of the mNWRT(qu) emerged.

In terms of predictors between subtests (table 69), no predictors emerged for the QCAP. The strongest predictor of each of the NWRTs(qu) was the corresponding NWRT(qu) test (i.e. Maltese with English). The DDFA was also found to be a predictor of the mNWRT(qu).

5.6.4.2 Auditory processing subtests using linguistic content. When considering the entire sample population, ‘pathology’ emerged to be either the sole predictor (as for the NWRTs(n)) or (most frequently) the strongest predictor in terms of the independent variables across all subtests using linguistic content. ‘Primary language’ also emerged as a predictor for both DD right ear scores, where the PL English speakers obtained higher percentage scores (figures 5.27 and 5.28). This pattern surfaced even when only the TD sample were entered into the model, where ‘primary language’ was the sole or strongest predictor in three out of four DD subtests. ‘Age group’ emerged as a significant predictor of the mNWRT(n), where the participants obtained improved scores with increasing age (figure 30).

Similarly to the NWRTs(qu), the NWRTs(n) were predicted best by their corresponding NWRT(n) test. The DDFA tasks were also predicted by the same task presented to the

opposite ear. However, the strongest common predictor of the DD(FA) was the mNWRT(qu). There was no common predictor of the DDFR task.

5.6.4.3 Auditory processing subtests using non-linguistic content. When the entire sample population was included in the GLiM, ‘pathology’ only emerged as a predictor of the DPT test. It did not emerge as a predictor of the FTP and the GIN tests, suggesting that the participants forming the clinical group children performed similarly to the TD group in this sample. When looking at the TD group no common predictor emerged for the DPT, FPT, and GIN (Ath) tests. ‘Age group’ emerged as a common predictor of the GIN (percentage correct) test, in which the scores improved with increasing age (figure 69).

The DPT and FPT were predicted by the same subtest presented to the opposite ear. The same pattern was observed in the GIN (Ath) and the GIN (percentage correct) scores. However, these subtests were predicted by further subtests within the assessment battery. The GIN (Ath) was also predicted by the GIN (% correct) as well as the mNWRT(qu), while the GIN (% correct) was predicted by the GIN (Ath) tested through the left ear as well as the SIT.

Table 68

Predictors of each subtest

<i>Test</i>	<i>Sub-test</i>	<i>Predictors</i>			
		Sample with only typically developing children		Total sample – typically developing and clinical sample	
		Test of model effects	Parsimonious model	Test of model effects	Parsimonious model
<i>QCap</i>	Total score	- none	- none	- pathology	- pathology

<i>SIT</i>	Total score	- age	- age	- age - pathology	- pathology
<i>mNWRT(qu)</i>	total % error	- region	- none	- none	- pathology
<i>eNWRT(qu)</i>	total % error	- school - age	- school (p= .002) - age (p=.025)	- none	- pathology
<i>mNWRT(n)</i>	total % error	- age	- age	- pathology	- pathology
<i>eNWRT(n)</i>	total % error	- none	- none	- none	- pathology
<i>Dichotic Digits Test (focused attention)</i>	Right ear	- primary language - region	- primary language	- primary language - region - pathology	- primary language (p=.025) - pathology (p=.004)
<i>% correct</i>	Left ear	- none	- none	- pathology	- pathology
<i>Dichotic Digits Test (free recall)</i>	Right ear	- primary language - age	- primary language (p=.002) - age (p=.007)	- primary language - pathology	- primary language (p=.005) - age (p=.022) - pathology (p=.008)
<i>% correct</i>	Left ear	- none	- primary language	- pathology	- pathology (p<.001) - school type (p=.018)
<i>Duration Patterns Test</i>	Right ear	- none	- none	- pathology - age	- pathology
<i>% correct</i>	Left ear	- none	- none	- pathology - age	- pathology (p<.001) - age (p=.022) - school (p=.033)
<i>Frequency Patterns Test</i>	Right ear	- none	- none	- none	- none
<i>% correct</i>	Left ear	- none	- school	- none	- none
<i>Gaps-in-Noise Test</i>	Right	- gender	- none	- gender	- gender
<i>Ath</i>	Left	- none	- none	- none	-age
<i>Gaps-in-Noise Test</i>	Right	- none	-age	-age - primary language	-age - primary language
<i>% gaps detected</i>	Left	- none	- age - primary language	-age - primary language	-age - primary language

Table 69

Predictors between subtests

Assessment	Assessments found to be significant predictors	Common significant predictors (where assessment results are analysed for left and right ears separately)
<i>mNWR</i> T (qu) – Total score	<ul style="list-style-type: none"> - <u>eNWR</u>T (qu): Total score (p<.001) - <u>Dichotic digits (FA): right</u> (p<.001) - <u>Dichotic digits (FA): left</u> (p=.007) - Dichotic digits (FR): right - Gaps in noise (Ath): left 	- <u>Dichotic digits (FA)</u>
<i>eNWR</i> T (qu) – Total score	<ul style="list-style-type: none"> - <u>mNWR</u>T (qu) - Total score (p<.001) - Gaps in noise (Ath): left 	
<i>mNWR</i> T (n) – Total score	<ul style="list-style-type: none"> - <u>eNWR</u>T (n): Total score (p=.002) - <u>mNWR</u>T (qu) - Total score (p=.003) - Dichotic digits (FA): left 	
<i>eNWR</i> T (n) – Total score	<ul style="list-style-type: none"> - <u>mNWR</u>T (n) - Total score (p=.003) - Gaps in noise (Ath): right - Gaps in noise (% correct): left 	
Questionnaire of (Central) Auditory Processing (QCap)	- no significant predictors	
Sentence Imitation Test	- Dichotic digits (FR): right	
Dichotic Digits Test (Focused Attention): Right ear	<ul style="list-style-type: none"> - <u>mNWR</u>T (qu) - Total score (p<.001) - <u>mNWR</u>T (n) - Total score - <u>Sentence Imitation Test</u> - QCap - <u>Dichotic digits (FA): left</u> (p=.019) - Frequency Patterns Test: left - Gaps in noise (% correct): right 	<ul style="list-style-type: none"> - <u>Dichotic digits (FA): opposite ear</u> - <u>mNWR</u>T (qu) - Total score
Dichotic Digits Test (Focused Attention): Left ear	<ul style="list-style-type: none"> - <u>Dichotic digits (FA): right</u> (p=.012) - <u>mNWR</u>T (qu) - Total score (p=.002) - Dichotic digits (FR): right 	
Dichotic Digits Test (Free recall): Right ear	<ul style="list-style-type: none"> - <u>Dichotic digits (FR): left</u> - <u>mNWR</u>T (qu) - Total score through phoneme analysis - Dichotic digits (FA): left - Gaps in noise (Ath): left 	No common significant predictors between ears
Dichotic Digits Test (Free recall): Left ear	- Gaps in noise (% correct): left	
Duration Patterns Test: right	<ul style="list-style-type: none"> - <u>Duration Patterns Test: left</u> - Qcap - <u>eNWR</u>T (n): Total score through phoneme analysis - Frequency Patterns Test: left - Gaps in noise (% correct): left 	- <u>Duration Patterns Test: opposite ear</u>
Duration Patterns Test: left	<ul style="list-style-type: none"> - <u>Duration Patterns Test: right</u> - Sentence Imitation Test 	

<i>Frequency Patterns Test: right</i>	<ul style="list-style-type: none"> - <u>Frequency Patterns Test: left</u> - <u>Qcap</u> - <u>Sentence Imitation Test</u> - Dichotic digits (FR): left - Dichotic digits (FA): right - Duration Patterns Test: right 	<ul style="list-style-type: none"> - <u>Frequency Patterns Test: opposite ear</u>
<i>Frequency Patterns Test: left</i>	<ul style="list-style-type: none"> - <u>Frequency Patterns Test: left</u> - Gaps in noise (Ath): left 	
<i>Gaps in noise (Ath): right</i>	<ul style="list-style-type: none"> - <u>Gaps in noise (Ath): left (p<.001)</u> - <u>Gaps in noise (% correct): right (p<.001)</u> - <u>Gaps in noise (% correct): left (p<.001)</u> - <u>mNWRT (qu) - Total score (p=.007)</u> - <u>Sentence Imitation Test</u> 	<ul style="list-style-type: none"> - <u>Gaps in noise (Ath): opposite ear</u> - <u>Gaps in noise (% correct): right</u> - <u>Gaps in noise (% correct): left</u> - <u>mNWRT (qu) - Total score</u>
<i>Gaps in noise (Ath): left</i>	<ul style="list-style-type: none"> - <u>Gaps in noise (Ath): right (p<.001)</u> - <u>Gaps in noise (% correct): right (p<.001)</u> - <u>Gaps in noise (% correct): left (p<.001)</u> - <u>mNWRT (qu) - Total score (p=.001)</u> - <u>eNWRT (qu) - Total score through phoneme analysis</u> - Dichotic Digits (FR): right 	
<i>Gaps in noise (% correct): right</i>	<ul style="list-style-type: none"> - <u>Gaps in noise (% correct): left (p<.001)</u> - <u>Gaps in noise (Ath): right</u> - <u>Gaps in noise (Ath): left (p<.001)</u> - <u>Sentence Imitation Test (p=.006)</u> 	<ul style="list-style-type: none"> - <u>Gaps in noise (% correct): opposite ear</u> - <u>Gaps in noise (Ath): left</u> - <u>Sentence Imitation Test</u>
<i>Gaps in noise (% correct): left</i>	<ul style="list-style-type: none"> - <u>Gaps in noise (Ath): left (p<.001)</u> - <u>Gaps in noise (% correct): right (p<.001)</u> - <u>Sentence Imitation Test (p<.001)</u> - <u>Qcap</u> - Duration Patterns Test: right 	

5.7 Discussion

In this section, the results will be discussed in relation to each of research questions 2, 3, and 4 separately.

5.7.1 Research question 2: How do typically developing Maltese children perform on tests of auditory processing? This study obtained data trends for an APD test battery on Maltese children. The subtests included some newly developed tasks, others adapted, and a few as designed originally. These data highlighted several key characteristics, which will be discussed in turn. In an attempt to address this research question, the reader is referred to tables 70 to 73, which present published norms and data of AP tests that have also

been used in this research. These include the temporal patterning and resolution tests, and the dichotic digits tests. The first thing that is evident is the variability in mean performance between studies. This is especially evident in the DPT and FPT (table 70). The DPT mean scores ranged between 22 to 54% correct in 7 - 9 year old children (Mattsson et al., 2017), and 54.82 to 90.3% correct in 7 to 12 year old children (Dau, 2011). The performance of the Maltese participants in this study fell in between this range (right: 63.33%; left: 64.29%) and was very similar to the findings of Hales' (2016) study on the local population. The FTP scores depict a similar picture. The reason for this variability might lie in the methodology of how the responses were requested. For example, in the Musiek (1983), Dau (2011) and McDermott et al. (2016) studies, the children were asked to verbally explain the DPT (by indicating the sequence in terms of 'long' and 'short') and FPT ('high' and 'low'). Mattsson et al. (2017) allowed both verbal explanation and humming of the tones, while this study as well as Hales (2016) both required the children to hum the FPT sequence and draw the DPT pattern. Less variation emerged between studies in the GIN (table 71) and the DD (table 72) tests. All studies presented in table 71 found GIN thresholds of between 4.3 and 5.65ms and mean percentage response correct of 66.5 and 76.2. The DD findings across studies (table 72) report right ear percentage correct scores of between 70 and 80% in children aged 7 to 9;11 years (Musiek, 1983), to between 91.65% and 96.13% in children aged 7 to 10 years (McDermott et al., 2016). Considering the already emerged literature that different components of the central auditory nervous system mature at different rates (McGee & Kraus 1996; Johnson, Nicol, Zecker, & Kraus, 2008; Muller, Gruber, Klimesch, & Lindenberger, 2009), the variations in these studies indicate different possible maturational rates across diverse paediatric populations. This highlights the importance of obtaining normative data specific to a population: for both non-linguistic and linguistic-based subtests.

Table 70

Overview of data emerging from this study and previous published data on temporal patterning tasks

	DPT (mean % correct)		FPT (mean % correct)	
	Right	Left	Right	Left
Current study	63.33	64.29	85.14	85.17
	(No age effects emerged in these tests)			
Bellis (2011)	25 (7-7;11 yrs)		35 (7-7;11 yrs)	
	35 (8-8;11 yrs)		42 (8-8;11 yrs)	
	54 (9-9;11 yrs)		63 (9-9;11 yrs)	
Hales (2016)	65.41	65.62	97.91	97.29
	(This study reports no ear, gender or age effects in these tests)			
Mattsson et al.(2017)	22.2 (7 yrs)	27.0 (7 yrs)	29.2 (7 yrs)	33.6 (7 yrs)
	25.8 (8 yrs)	30.3 (8 yrs)	35.0 (8 yrs)	38.6 (8 yrs)
	39.9 (9-10 yrs)	45.3 (9-10 yrs)	48.3 (9-10 yrs)	49.3 (9-10 yrs)
Musiek (2002)			40 (8;00 – 8;11 years)	
			65 (9;00 – 9;11 years)	
McDermott et al (2016)	61.07 (7-8 yrs)	60.39 (7-8 yrs)	74.64 (7-8 yrs)	74.64 (7-8 yrs)
	75.97 (9-10 yrs)	78.16 (9-10 yrs)	87.15 (9-10 yrs)	86.16 (9-10 yrs)
	85.69 (11-12 yrs)	85.53 (11-12 yrs)	89.15 (11-12 yrs)	88.47 (11-12 yrs)
Kelly (2007)	--	--	72.62 (7-8 yrs)	71.02 (7-8 yrs)
			85.22 (9-10 yrs)	87.27 (9-10 yrs)
			91.4 (11-12 yrs)	92.7 (11-12 yrs)
Dau (2011)	54.82 (7-8 yrs)	57.04 (7-8 yrs)	76.3 (7-8 yrs)	77.04 (7-8 yrs)
	81.67 (9-10 yrs)	84.17 (9-10 yrs)	90.83 (9-10 yrs)	90.83 (9-10 yrs)
	90.3 (11-12 yrs)	89.09 (11-12 yrs)	95.76 (11-12 yrs)	91.52 (11-12 yrs)

Table 71

Overview of data emerging from this study and previous published data on temporal resolution tasks

	GIN (mean Ath) (ms)		GIN (mean % correct)	
	Right	Left	Right	Left
Current study	5.30	5.10	66.47 (7-7;11 yrs) 67.54 (8-8;11 yrs) 73.14 (9-9;11 yrs)	68.74 (7-7;11 yrs) 72.95 (8-8;11 yrs) 73.93 (9-9;11 yrs)
Cassar (2014)	4.95	5.15	69.32	69.73
	(This study reports no ear, gender or age effects in these tests)			
Hales (2016)	4.75	4.81	76.19	75.20
	(This study reports no ear, gender or age effects in these tests)			
Mattsson et al.(2017)	5.1 (across both ears and ages 7 to 12 years)		--	--
Amaral & Colella-Santos (2010)	4.7	4.4	73.2	74.1
	(Across genders. Age group: 8-10 years)			
Amaral, Martins & Colella-Santos (2013)	4.32	4.43	73.3	74.6
	(Across genders. Age group: 8-10 years)			
Shinn, Chermak & Musiek (2009)	5.36 (7 yrs) 5.0 (8 yrs) 4.60 (9 yrs)	5.0 (7 yrs) 4.73 (8 yrs) 5.10 (9 yrs)		
Bareira, Silva, Branco-Barreiro & Samelli (2011)		5.65 (7 yrs) 5.12 (8 yrs) 4.87 (9 yrs)		

Table 72

Overview of data emerging from this study and previous published data on the dichotic digits tasks

	DDFR (% correct)		DDFA (% correct)			
	Right	Left	Right	Left	Right	Left
Current study	88.75 (7-7;11 years)	} significant age effects	86.95 (7-7;11 years)	} did not reach significance		
	94.86 (8-8;11 years)		88.82 (8-8;11 years)			
93.88 (9-9;11 years)	87.67 (9-9;11 years)					
	90.94 (PL Maltese)	} significant language effects	86.83 (PL Maltese)	} significant language effects	92.14 (PL Maltese)	} significant language effects
	94.76 (PL English)		91.65 (PL English)		96.41 (PL English)	
					89.02 (PL English)	} did not reach significance
Kelly (2007)	87.95 (7-8 yrs)		85.27 (7-8 yrs)		--	--
	93.20 (9-10 yrs)		91.24 (9-10 yrs)			
	94.4 (11-12 yrs)		94.3 (11-12 yrs)			
Mattsson et al.(2017)	77.3 (7 years)		64.6 (7 years)		--	--
	86.8 (8 years)		74.1 (8 years)			
	88.6 (9-10 years)		80.6 (9-10 years)			
McDermott et al. (2016)	91.65 (7-8 yrs)		88.08 (7-8 yrs)		--	--
	96.13 (9-10 yrs)		92.81 (9-10 yrs)			
	97.49 (11-12 yrs)		95.75 (11-12 yrs)			
Dau (2011)	90.28 (7-8 yrs)		92.22 (7-8 yrs)		--	--
	96.56 (9-10 yrs)		93.13 (9-10 yrs)			
	99.32 (11-12 yrs)		97.5 (11-12 yrs)			
Rosenberg (2011)	73.9 (7-7;11 yrs)		61.3 (7-7;11 yrs)		--	--
	79.9 (8-8;11 yrs)		70.6 (8-8;11 yrs)			
	81.7 (9-9;11 yrs)		75.0 (9-9;11 yrs)			
Musiek (1983)	70 (7-7;11 yrs)		55 (7-7;11 yrs)		--	--
	75 (8-8;11 yrs)		65 (8-8;11 yrs)			
	80 (9-9;11 yrs)		75 (9-9;11 yrs)			

The results obtained for the APD subtests in the Maltese TD sample showed varying effects of some independent variables, with the most prominent ones being ‘age’ and ‘primary language’. The regression analyses (table 68) highlighted ‘age’ as a predictor of the Maltese NWRT in noise. As was illustrated (figure 30), the performance of the children improved with increasing age in both English and Maltese subtests, with the latter reaching significance. Similar outcomes have already been reported. Age effects for speech-in-noise tests have been found using various stimuli, such as monosyllabic words (McDermott et al., 2016; Keith, 2000; Neijenhuis, Snik, Priester, Kordenoordt & van den Broek, 2002), short utterances (Mattsson et al., 2017), high and low predictability sentences (Elliott, 1979), and nonword syllables (Moore et al., 2010). This has been attributed to maturation of the central auditory nervous system (Keith, 2000; Stollman, van Velzen, Simkens, Snik, & van den Broek, 2004).

The effect of ‘age’ also emerged in one temporal processing task: the GIN, when scored in terms of ‘percentage correct’, but not when the GIN was scored in terms of smallest gap detection (Ath). The results of this study are partly consistent with previous reports. Various studies have found no effects of age (Barreira et al., 2011; Shinn et al., 2009), with some studies reporting this across both scoring methods (‘Ath’ and ‘percentage correct’) both in Maltese children (Cassar, 2014; Hales, 2016) as well as in other paediatric populations (e.g. Amaral, & Colella-Santos, 2010; Amaral, Martins, & Colella-Santos, 2013; Perez & Pereira, 2010). This difference suggests that while the Maltese children in this sample demonstrate similar gap detection thresholds across age, the younger cohorts tend to make more errors. The contrasting results between the previous local studies (Cassar, 2014; Hales, 2016) and this research regarding whether age might predict outcomes on the GIN might be due to the difference in the sample size of the groups taking part in each study. Both

Cassar and Hales' studies were rather small scale compared with the current study.

Nevertheless, this contrast warrants the need for further investigation in this area.

Primary language effects emerged in the dichotic digits task where the PL English group obtained higher scores than the PL Maltese group. This outcome seems to be consistent with Gordon and Zatorre's (1981) finding that individuals tend to perform better on dichotic tasks presented in their primary language. Yet, with the vast majority of Maltese children being bilingual by 7 years of age, and with most children choosing to express themselves in English when saying numbers, this outcome is perhaps surprising.

The effect of school type on the APD subtests did not emerge for this population, indicating that children perform similarly on these tests irrespective of the school they attend. Having said this, there was a 'school type' effect on one subtest of language processing: the English NWRT in quiet. The children attending a church school performed best and those attending a state school performed the poorest. It may be argued that this outcome could be due to the small amount of participants attending state schools who speak English as their PL, compared with a somewhat more balanced PL distribution in the 'church school' participants (see figures 3 and 4 in chapter 3: Methodology). While it is a typical occurrence that the majority of Maltese children attending state schools are primarily Maltese speaking and those attending church schools tend to be more balanced in terms of PL (Agius, 2012) (hence the randomly occurring PL distribution of the participants), further research using larger samples would confirm this effect or otherwise.

Finally, the effect of 'gender' did not emerge for this population. This outcome is consistent with previous literature reports across various populations (e.g. Keith 2000; Fuente and McPherson 2006; Mattsson et al., 2017; McDermott et al. 2016; Pedersen, Dahl-Hansen,

& Christensen-Dalsgaard, 2017), and suggests that that trends separated on the basis of ‘gender’ should not be essential.

5.7.2 Research question 3: How do children diagnosed with neurodevelopmental disorders perform on tests of auditory processing? With a substantial body of research reporting co-occurring symptoms in children with a neurodevelopmental disorder (as was described in section 2.9 of chapter 2: Literature review), it was of interest to investigate the performance of Maltese children with this diagnosis (clinical group) in comparison with the TD sample.

When a regression analysis included the entire sample (table 68), the ‘pathology’ variable emerged as the strongest predictor for the questionnaire (QCAP) - indicating that parents of children with various reported neurodevelopmental disorders perceive their children has having greater listening difficulties than their TD counterparts, as well as all the APD subtests using linguistic content. The aim of the QCAP development and use was to extract any listening difficulties that the children might have. The outcomes of this research show that the clinical group were reported by their carers to exhibit significantly greater listening difficulties. This corroborates with other research findings of greater reported listening difficulties in children with DLD (Azzopardi, 2015; Ferguson et al., 2011; Tabone et al., 2016), literacy difficulties and ADHD (Tabone et al., 2016). The clinical group in this study also performed worse than the TD cohort on the subtests using linguistic content, namely the dichotic listening tests and speech in noise, suggesting that the listening difficulties emerging through the questionnaire also surfaced in these subtests. This might not be surprising when considering that several questions in the QCAP targeted difficulties with understanding longer and more complex sentences, and speech in noisy environments. The auditory processing skills in local clinical populations have already been investigated through publications and dissertations (supervised by the researcher) using the same subtests as this

research. Tabone et al.'s (2016) results were coherent with this research. They report a significantly weaker performance bilaterally in Maltese children with DLD and ADHD on the dichotic listening tasks and a poorer left ear performance in children with literacy difficulties. Poor performance on the dichotic listening tasks in children with DLD has also been reported in other populations using different stimuli, such as digits (Miller & Wagstaff, 2012), CV syllables (Cohen, Riccio & Hynd, 1999) and words (Dlouha, Novak & Vokral, 2007). Azzopardi's (2015) study on the AP skills in Maltese children with DLD brought out contrasting findings. In this study no group differences emerged between the clinical and control group on the dichotic digits task. While the author acknowledged a limitation of a very small sample population in the study, these conflicting findings on the Maltese paediatric population warrant further research with the aim of obtaining a clearer picture of dichotic listening in this clinical group. Tabone et al. also found a weaker performance by the DLD group on both NWRT in noise tasks and the group with literacy difficulties on the Maltese NWRT in noise. The children with ADHD did not register a strikingly weaker execution in this task. Azzopardi's (2015) findings on children with DLD were consistent only for the younger cohorts. Findings showed a significantly weaker performance by the 7 and 8 year old children in the Maltese NWRT in noise, and the 7 year old children in the English NWRT in noise. This outcome tentatively indicates that with increasing age the perception of speech in noise improves in children with DLD, closing the gap with their TD peers. Azzopardi's finding is also consistent with Ferguson et al. (2011) who found no significant difference in performance of VCV syllable repetition in noise between children with DLD and their mainstream school counterparts.

With claims that impaired auditory temporal processing could underlie disorders of language and literacy (e.g. Tallal, 2000; Tallal & Stark, 1981; Tallal, Miller, & Fitch, 1993) (see section 2.12.1) and ADHD (Radonvich & Mostofsky, 2004; Van Meel, Oosterlaan,

Heslenfeld & Sergeant, 2005) (see section 2.9.2), it was of interest in this research to investigate whether performance on the Duration and Frequency Patterns test, and the Gaps in noise test would vary significantly in the TD and clinical groups. The 'pathology' variable only emerged as a predictor of the DPT, in which the clinical group obtained significantly worse scores than the TD group. The DPT was the only subtest that featured under both factors in the factor analysis (see table 5.8 of section 5.2.1, *Chapter 5: Quantitative analysis*), suggesting that the method with which the children were asked to perceive and show the difference in the duration of the tones (long / short) might have tapped into both non-linguistic and linguistic-based processing. One way of discussing this is to propose that the children forming the clinical group exhibited difficulties in temporal processing specific to the perception of duration differences. The Tabone et al. (2016) study compared the temporal processing skills of Maltese TD children and those of children diagnosed with ADHD, language impairment, and literacy difficulties. Their results were partly consistent with this research, where they also demonstrated that the children in each clinical group did not perform statistically worse than the control in the FPT and GIN. However, in contrast to this research, their findings also extended to the DPT. Then again, Azzopardi's (2015) findings were partly in agreement. While she too reported no statistically significant differences between TD and DLD groups in the FPT and GIN performance, a significant difference in one age group (the 8-year-old) emerged in the DPT, showing a better performance by the TD participants. While all these local studies adopted the same tests and administrative methodologies, the result variations could be attributable to the participant differences. For example, Azzopardi's (2015) study consisted of a relatively small sample in contrast to this research, which might have posed a limitation with respect to the strength of her results. Another evident difference is that this research analysed the results of the clinical group as a whole, unlike Tabone et al. (2016), who divided and analysed the participants separately in

terms of their diagnoses. Having mentioned this, it still should not be excluded that this variability might also stem from the already emerged findings that not all individuals with language, literacy or attention difficulties have temporal processing deficits (Bishop et al., 1999; Ramus, 2003). The variation in findings of temporal processing skills in these clinical groups is not limited to local research. As was already reviewed in section 2.9 (Chapter 2: literature review), while there have been findings across different populations of weaker performance on the temporal processing tasks in children with DLD (Fortunato-Tavares et al., 2009; Tallal, 2000), literacy difficulties (Fostick, Bar-El, & Ram-Tsur, 2012; Simões & Schochat, 2010; Soares, Sanches, Alves, Carvallo & Cárnio, 2013; Vandermosten et al., 2011), and ADHD (Abdo, Murphy & Schochat, 2010), contrasting outcomes of no significant differences between TD and clinical groups have also been reported (e.g. Bishop, Carlyon, Deeks & Bishop, 1999; Norrelgen, Lacerda, & Forssberg, 2002; Radonovich & Mostofsky, 2004).

5.7.3 Research question 4: Is there a predictive relationship between any auditory processing subtest and (a) any language subtest (b) the questionnaire of (central) auditory processing? Throughout this section, the significant correlations and predictors are discussed. Table 69 highlights subtests that emerged as predictors of other subtests. There were instances where one subtest emerged as a predictor of only part of another subtest. For example, the Sentence Imitation Test and the QCAP were found to be predictors of the Dichotic Digits (focused attention) test, but only on the right side. The opposite situation was also evident, where only one part of a subtest emerges as a predictor of another subtest. For example, the performance of the Gaps in noise test (Ath) on the left side only predicted performance on the Maltese NWRT in quiet. In light of the several ‘part-predictors’ that occurred, this discussion will only take into consideration the strongest predictors, i.e. those subtests which emerged as predictors of other subtests in their entirety.

The most prominent finding was that the tasks that investigate the same or similar skills are significantly correlated (see table 67). This was evident both across languages and ears. There were significant correlations between the tests of language processing (the Maltese and English NWRT in quiet, and the SIT) and the subtests using linguistic content (the Maltese and English NWRT in noise, and the Dichotic Digits tests). Looking at for example, the Maltese NWRT in quiet, its strongest significant correlation was the English-based counterpart test ($R_S = .562, p < .01$). It also correlated significantly (at the 0.01 level) with the Maltese and English NWRT in noise, the SIT and the Dichotic Digits (focused attention) test. This demonstrated that a good performance in one test results in a similar good performance in another. These correlation outcomes are perhaps not surprising, given that nonword repetition, sentence imitation, and dichotic listening tasks all share a common underlying mechanism: working memory (Colflesh & Conway, 2007; Engle, 2002; Riches, 2012; Stokes, Wong, Fletcher & Leonard, 2006). The regression analysis that followed (table 68) revealed the English NWRT in quiet and the Dichotic Digits (focused attention) task as the strongest predictors of this test. Likewise, the Maltese NWRT in quiet emerged as a predictor of the Dichotic Digits (focused attention) (along with the DD(FA) score of the opposite ear), indicating a strong relationship between these auditory and language processing subtests. Correlations between language and working memory have frequently been reported (e.g. Baddeley, 2003; Daneman & Merikle, 1996; Gathercole, Willis, Emslie, & Baddeley, 1992). For example, significant correlations have been found between vocabulary and nonword repetition (Gathercole et al., 1992) and sentence imitation (Grech et al., 2011). A strong correlation has also been reported between dichotic listening and language comprehension (Asbjørnsen & Helland, 2006). The correlations and predictors that emerged from this research are consistent with these studies, thus adding on to the body of

research showing a association between performance on tasks of working memory and language abilities.

An unexpected relationship emerged between non-linguistic based APD subtests and some subtests of language processing. Specifically, results from the regression analysis showed that performance on the mNVRT(qu) predicted performance on the GIN(Ath), and performance on the SIT predicted performance on the GIN (% correct). It suggests that outcomes of these predictor variables have an influence on the respective dependent variables (Laerd Statistics, 2013). However, the extent of the predictions is indicated by the effect size of the correlation (Stangor, 2014). As is shown in table 5.42, there were no significant correlations between these tests (except for one weak correlation between the SIT and the left sided GIN (% correct)). Furthermore, all correlations were weak. This suggests that although the mNVRT(qu) and the SIT can be used to predict the GIN(Ath) and the GIN(% correct) respectively, the correlation coefficient does not give a good estimate of the degree to which this is possible (Stangor, 2014).

Although the QCAP did not emerge as a predictor of any APD or language processing subtest, there were significant correlations with the DD(FA) task as well as the SIT. As has already been mentioned, dichotic listening and sentence imitation both require working memory in order to execute them as a task. Working memory has been described as a multifaceted system. It is linked to the execution of complex tasks such as those involving attentional control to suppress less important information, or tasks that involve storage and processing (Engle, 2002; Riches, 2012). Accordingly, a good working memory capacity is linked to better ability to use attention to avert distraction (Engle, 2002). This correlation result should be expected since, on examination of the rotated component matrix for the QCAP (table 60), the largest component ('component 1') is made up of questions related to auditory attention and memory. So if a child is to score poorly in the questionnaire, there is

an increased chance that a high proportion of the weak scores fall within ‘component 1’. In this case the child might also score poorly on the Dichotic Digits (Focused Attention) test and the SIT. The term ‘might’ is used in light of the poor correlation between the QCAP and each of the assessments, albeit the correlations emerging as statistically significant ($R_S = -.233$ and $-.297$, $p < .01$ for the DD right and left attention focus respectively; $R_S = -.288$, $p < .01$ for the SIT). Further research on a larger typically developing and clinical population could further strengthen this correlation or otherwise.

5.7.4 Conclusion. Throughout this section the quantitative results were discussed in relation to the pertinent literature. The main outcomes are summarised below:

- The variations in results between findings were highlighted and attributed to methodological differences across studies. This outcome emphasises the necessity of collecting population-specific normative data in both subtests using linguistic and non-linguistic stimuli.
- The effect of ‘age’ emerged for the speech-in-noise test in this study. This outcome is consistent with research reporting age effects using monosyllabic words (McDermott et al., 2016; Keith, 2000; Neijenhuis, Snik, Priester, Kordenoordt & van den Broek, 2002), short utterances (Mattsson et al., 2017), high and low predictability sentences (Elliott, 1979), and nonword syllables (Moore et al., 2010).
- In contrast to other studies, this research also found ‘age’ effects in the test of temporal resolution – GIN. The significant difference was attributed to the increased errors that emerged in the younger age group of this sample.
- Consistent with previous studies, there were no ‘gender’ effects on any of the APD subtests.
- The clinical group in this study performed worse than the TD cohort on the QCAP. This outcome seems to corroborate earlier research outcomes of greater reported listening

difficulties in children with DLD (Azzopardi, 2015; Ferguson et al., 2011; Tabone et al., 2016), literacy difficulties and ADHD (Tabone et al., 2016).

- This research highlights differences in performance on the AP subtests using linguistic content between the clinical and TD groups. The clinical group also performed significantly worse on one test using non-linguistic content - the DPT, but not on the other tests of temporal processing. These results are partly consistent with earlier local research. The variations that emerged warrant further studies using larger samples of clinical groups.
- As was expected, the tasks that investigate the same or similar skills were significantly correlated. Correlations that emerged across the subtests (i.e. nonword repetition, sentence imitation, and dichotic listening) were found to share a similar underlying mechanism (working memory). Similar correlations have previously been reported in the literature (e.g. Asbjørnsen & Helland, 2006; Baddeley, 2003...).

This test battery incorporated both auditory and language processing tasks, the quantitative results of which have been presented and discussed. The following chapter presents a more qualitative analysis of the language processing subtests, where the results for NWRTs in quiet and the SIT are presented through an error analysis. The results are then discussed in relation to the relevant literature.

Chapter 6. Results – Content (Qualitative) Analysis

6.0 Chapter overview

This chapter focuses on the error analysis of the subtests within the assessment battery that were developed or chosen to tap into the children's language processing skills. These include the Maltese and English NWRT(qu) and the SIT. Chapter 5 examined the strongest predictors of the NWRT subtests as well as the SIT. It revealed that the independent variable '*pathology*' was the strongest significant predictor of these subtests. In light of this, an error

analysis of each is presented in terms of this significant predictor. Throughout this chapter, the children grouped as having ‘*no pathology*’ will be referred to as the typically developing (TD) group, and their performance on these tasks will be compared with those grouped under ‘*pathology*’ (referred to as the clinical group).

6.1 Nonword repetition tasks

6.1.1 Maltese Nonword Repetition in Quiet: eNWRt(qu). The TD participants were found to fare equally when considering the syllable length of the nonwords (figure 100). When comparing this with the participants forming the clinical group, one would find that on average they produced more errors, with the highest percentage error occurring in the 4-syllable nonwords in both Maltese and English subtests. Both groups were found to make most errors in the consonant clusters (CC), followed by the consonant sequences (CS⁶⁷). A detailed explanation of all the error types is presented in appendix D, tables 122 and 123 in relation to the TD group and the clinical group, respectively. These tables display the target word and child production when this deviates from the target. They further present the amount of times each error occurs (frequency), the level at which the error occurs (phoneme (P) or syllable (S) level), the type of emerged error as was explained in section 3.6.2.2 (*Chapter 3: Methodology*), and whether the nonword structure was preserved (P) or changed (C), in which case the target and changed structure were presented. The error types common to both groups are highlighted in grey. So for example, in table 73 it can be deduced that the target nonword ‘*niċċula*’ (IPA equivalent: /nitʃ:ula/) was produced 12 times as /itʃ:ula/. This error occurred at a phonological level (specifically due to the consonant deletion (omission) of syllable initial /n/) and caused the syllable structure to change from CVCCVCV to VCCVCV.

⁶⁷ CS refers to adjacent consonants across syllable boundaries.

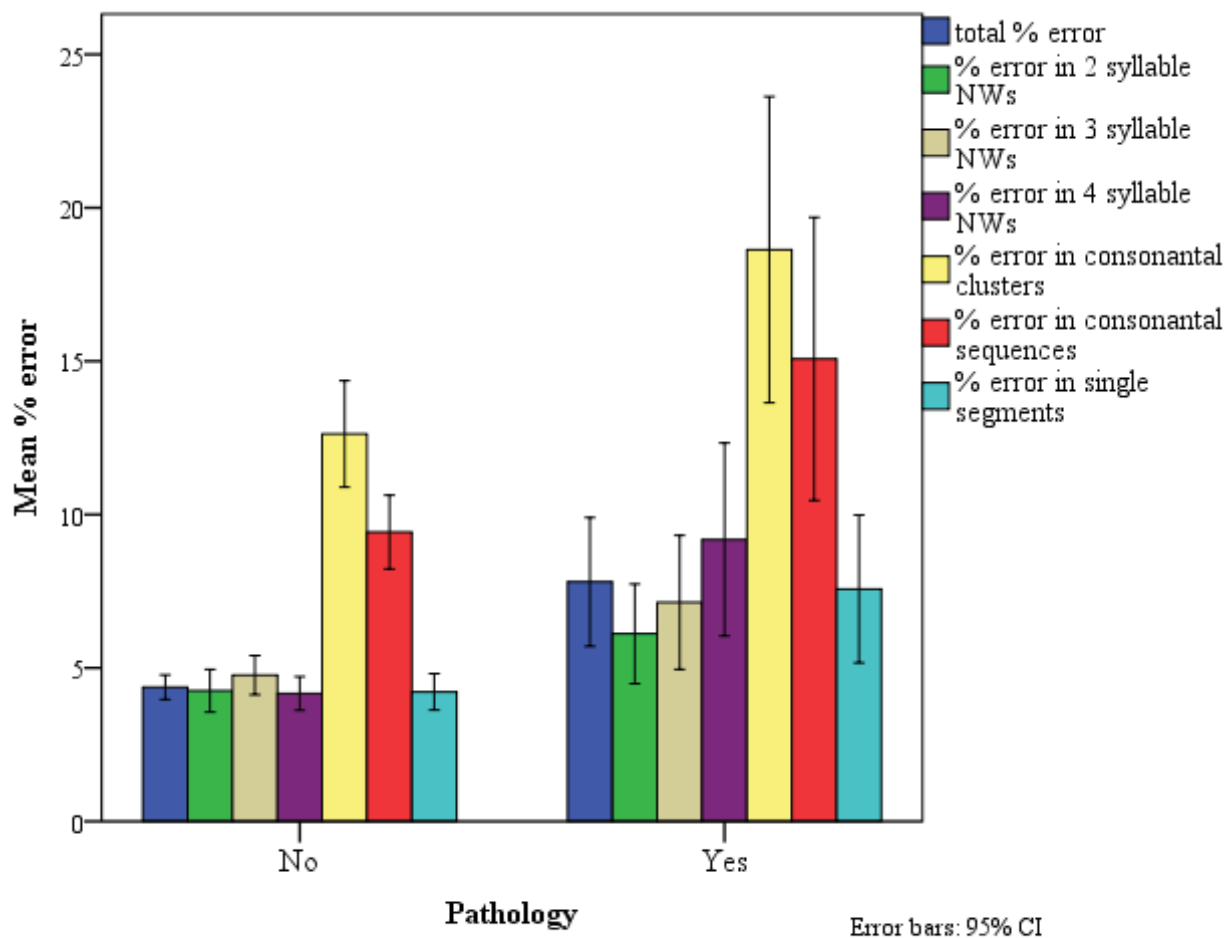


Figure 100 eNVRT(qu) percentage error across syllable length and word complexity

The patterns that emerged in table 122 of appendix D show that in the errors made by TD group were mainly structure preserving (68.8% of the errors). It also demonstrated that more errors occurred at the syllable initial position (68.3%). The vast majority were at a phoneme level (94.5%), with only a few (5.5%) errors occurring at the syllable level. Figure 101 highlights the percentage of occurrence for each phonological error that emerged for this group. This demonstrates that the highest amounts of phonological errors were of devoicing (systemic) and cluster reduction (structural). Table 122 of appendix D shows that much of the devoicing error is attributable to a high number (66) of devoicing in the geminate /v:/ present

in the nonword /ɾɛv:ɔfijɑ/ to /ɾɛf:ɔfijɑ/, while a large number (52) of the cluster reduction error occurred syllable finally in the nonword /lɪ'rɑntʃ/ to /lɪ'ratʃ/.

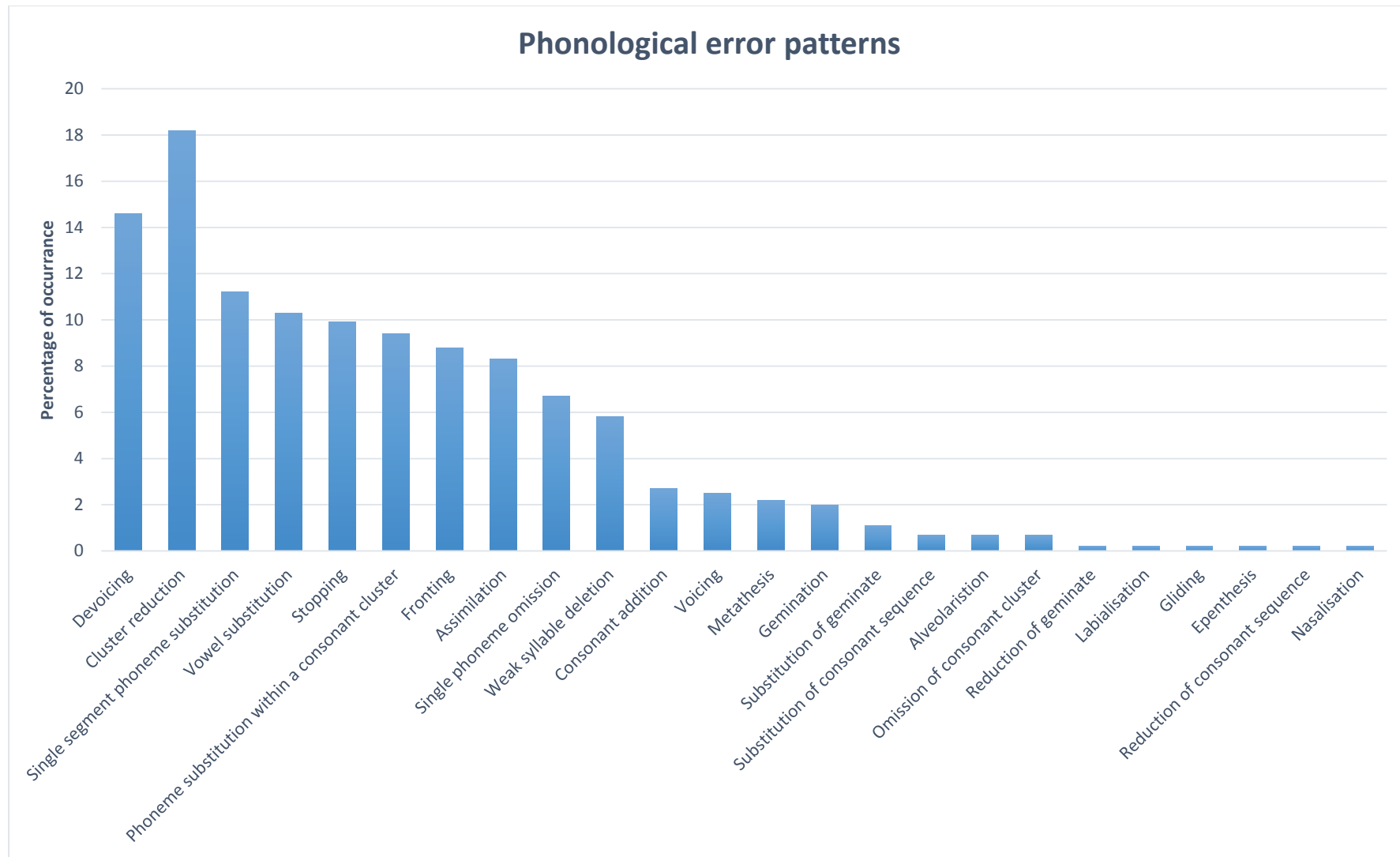


Figure 101 Percentage of occurrence of the error patterns produced by the TD group in the eNVRT

The phonological errors produced by the children in the clinical group are presented in table 123 (appendix D). Although this group produced significantly more errors in the nonword repetition tests, similarities in the error patterns between the two groups were evident. Most errors were structure preserving (63.6% of the errors), and in the syllable initial position (65%). The majority were also at a phoneme level (90.7%), compared with errors occurring at the syllable level (9.3%), although a slightly higher amount of errors occurring at the syllable level was evident in the clinical group. Figure 102 presents the percentage of occurrence for each phonological error that emerged in this group. There was a lower percentage of occurrence in devoicing, stopping, fronting, and phoneme substitutions within the consonant cluster when compared with the TD group. On the other hand, the clinical group presented with a higher percentage of occurrence in vowel substitution, weak syllable deletion, gemination, and deaffrication errors. There were also some errors that did not emerge at all in the TD group, namely affrication, deaffrication, vowel addition, and diphthong substitution. The percentage of occurrence for the clinical group is presented graphically in figure 102, while figure 103 combines the percentage of occurrence of each error type for the two groups in order to highlight similarities and differences in the percentage frequency of each error produced. The reader is referred to table 123 (appendix D) for an in-depth explanation of the errors produced by the clinical group.

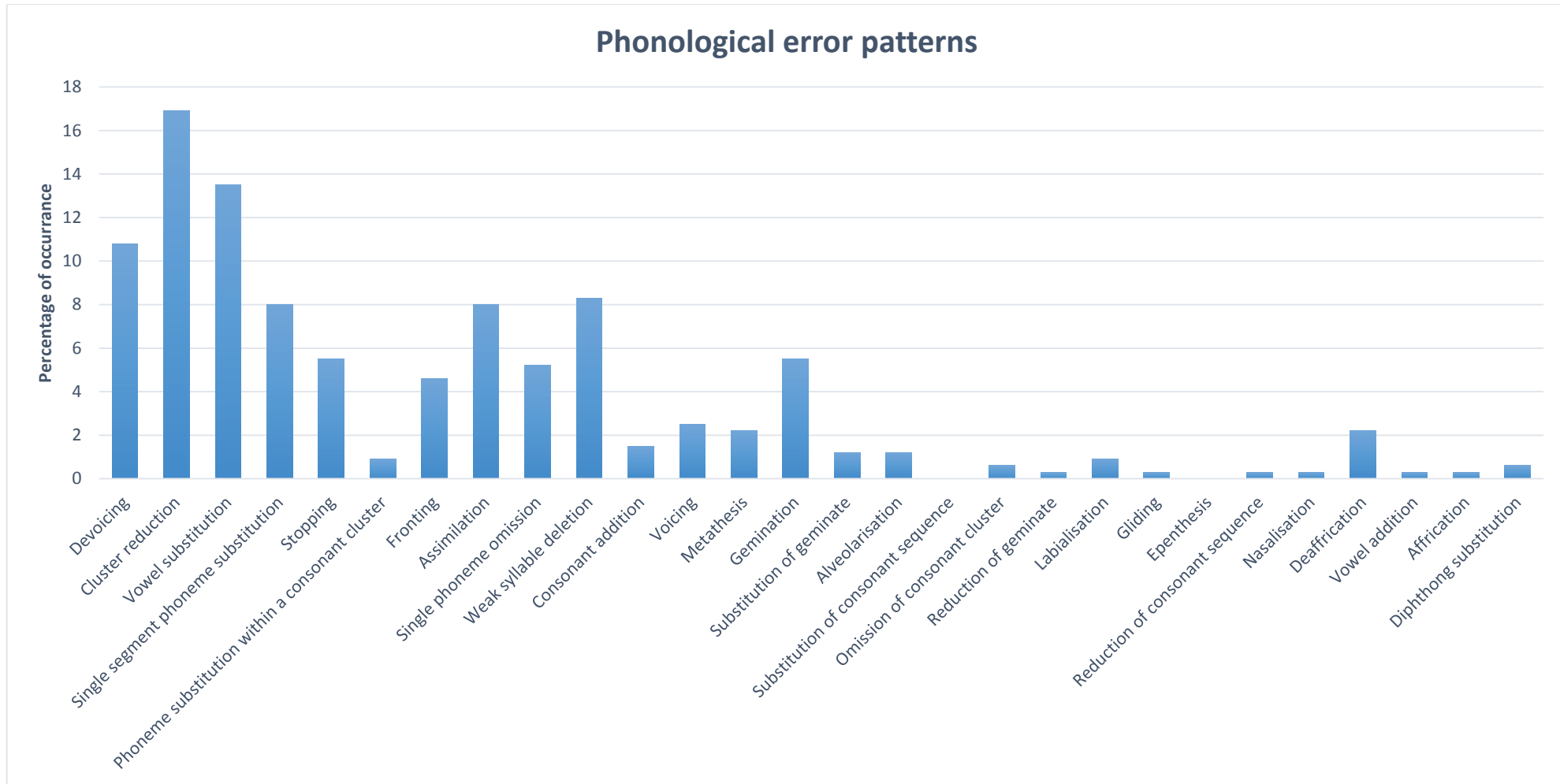


Figure 102 Percentage of occurrence of the phonological errors produced by the clinical group in the mNVRT

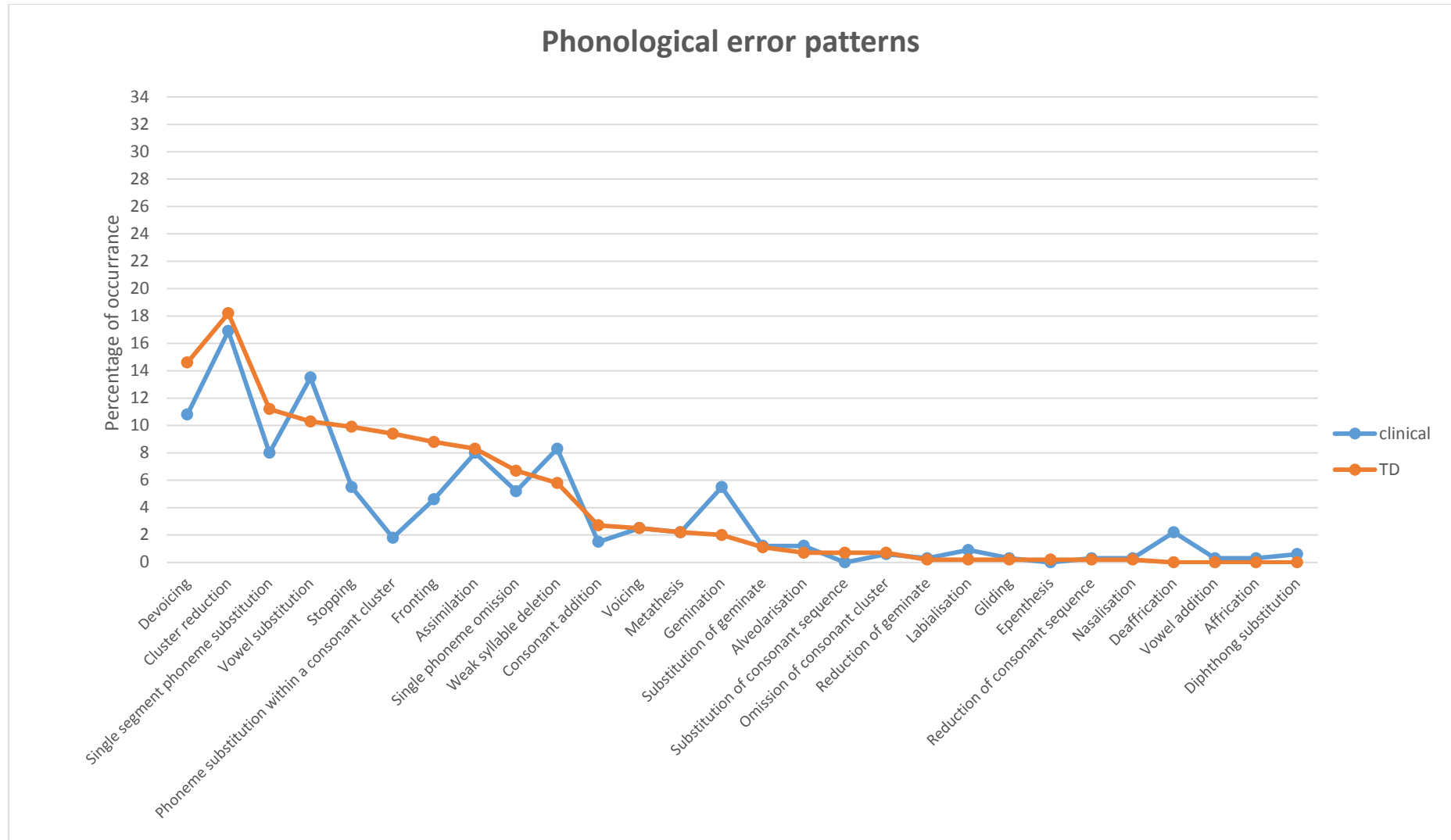


Figure 103 Overlay: Percentage of occurrence of the error patterns produced by both groups in the mNVRT

6.1.2 English Nonword Repetition in Quiet: eNWRT(qu). The participants' performance in the English-based NWRT displayed a similar pattern to the Maltese one (as shown in figure 104). The syllable length did not have an effect on the mean percentage error of the TD group. On the other hand, the clinical group were found to produce more errors in the 4 syllable nonwords. In both groups, most errors were evident in the CCs, with the clinical group displaying a much higher mean percentage error than the TD group. A similar result was evident in the CS. While both groups exhibited a lower percentage error in comparison with the CC, the clinical group displayed a much higher percentage error score.

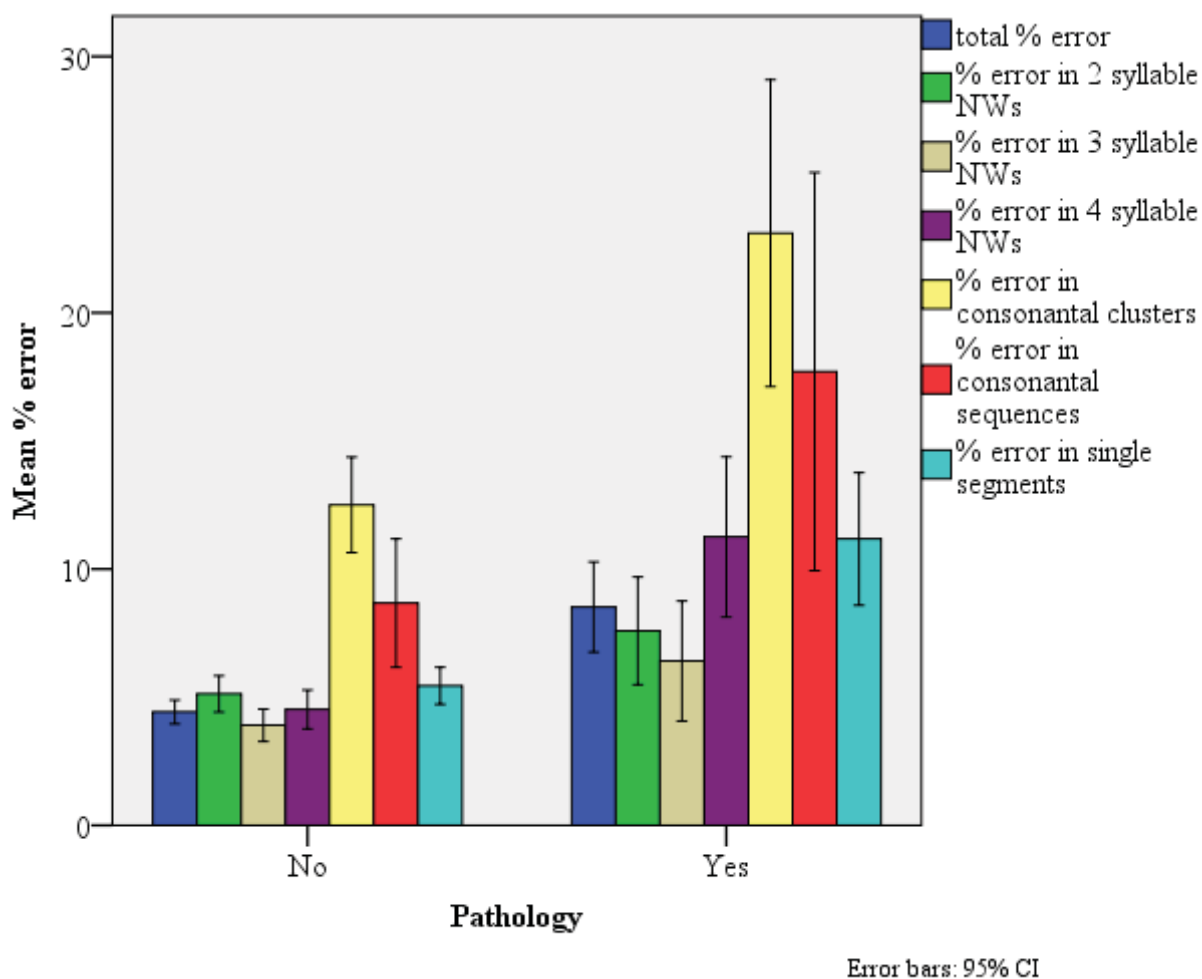


Figure 104 eNWRT(qu) percentage error across syllable length and word complexity

The reader is referred to table 124 of appendix D for an in-depth analysis of the phonological errors that emerged during the eNWRT(qu) task in the TD group. A higher percentage of structure preserving errors (78.8%) (when compared with structure changing errors), as well as those occurring at the syllable initial position (57%) also emerged in this task. Almost all errors emerged at the phoneme level (99.6%). The percentage of occurrence for each error as exhibited by the TD group is shown in figure 105. The highest percentage of errors was of vowel substitution. Errors such as labialisation of phonemes, cluster reduction, assimilation, as well as other phoneme substitutions were also prominent in this group. Much of the vowel substitutions occurred in one nonword, /krʌkɒdə:d/, where the /ʌ/ was substituted with /ɒ/ 39 times and the /ə:/ was substituted with /ɪ/ 26 times. The highest amount of cluster reduction was attributable to a high number (47) in the syllable final position of the nonword /tʃəmənt/ to /tʃəmət/, while the most assimilation emerged in the nonword /prɒ'mɪfɪtəs/, where it was produced as /prɒ'mɪtɪtəs/.

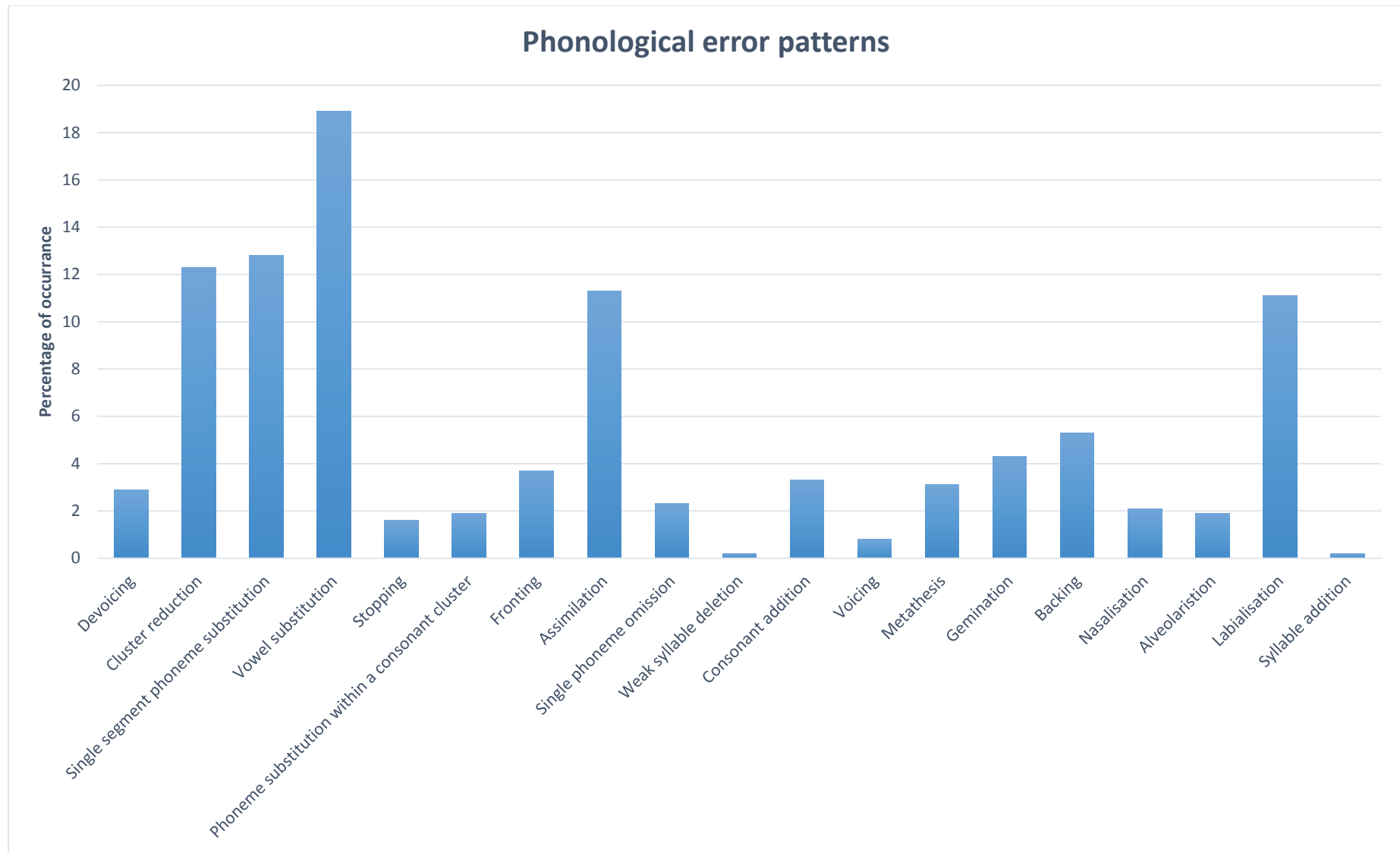


Figure 105 Percentage of occurrence of the phonological errors produced by the TD group in the eNVRT

Table 125 of appendix D provides a detailed account of the phonological errors that emerged in the eNVRT(qu) from the clinical group. Once again, a similar profile to the TD emerged, with a higher percentage of structure preserving errors (75.3%), and errors at the syllable initial position (69%). While most errors also occurred at the phoneme level (96.7%), a slightly higher amount of errors (substitutions and omissions) occurred at the syllable level when compared with the TD group. This pattern was also evident in the eNVRT(qu). The percentage of occurrence for each phonological error that emerged in this group is illustrated in figure 106. There was a noticeable lower percentage of occurrence in vowel substitutions, and labialisation, and a higher percentage of occurrence in alveolarisation, nasalisation, and weak syllable deletion when compared with the TD group. Some errors emerged in the clinical group that were not present in the TD group – specifically, syllable addition, gliding, denasalisation and deaffrication. However, these were of a low percentage of occurrence. Figure 107 highlights these similarities and differences.

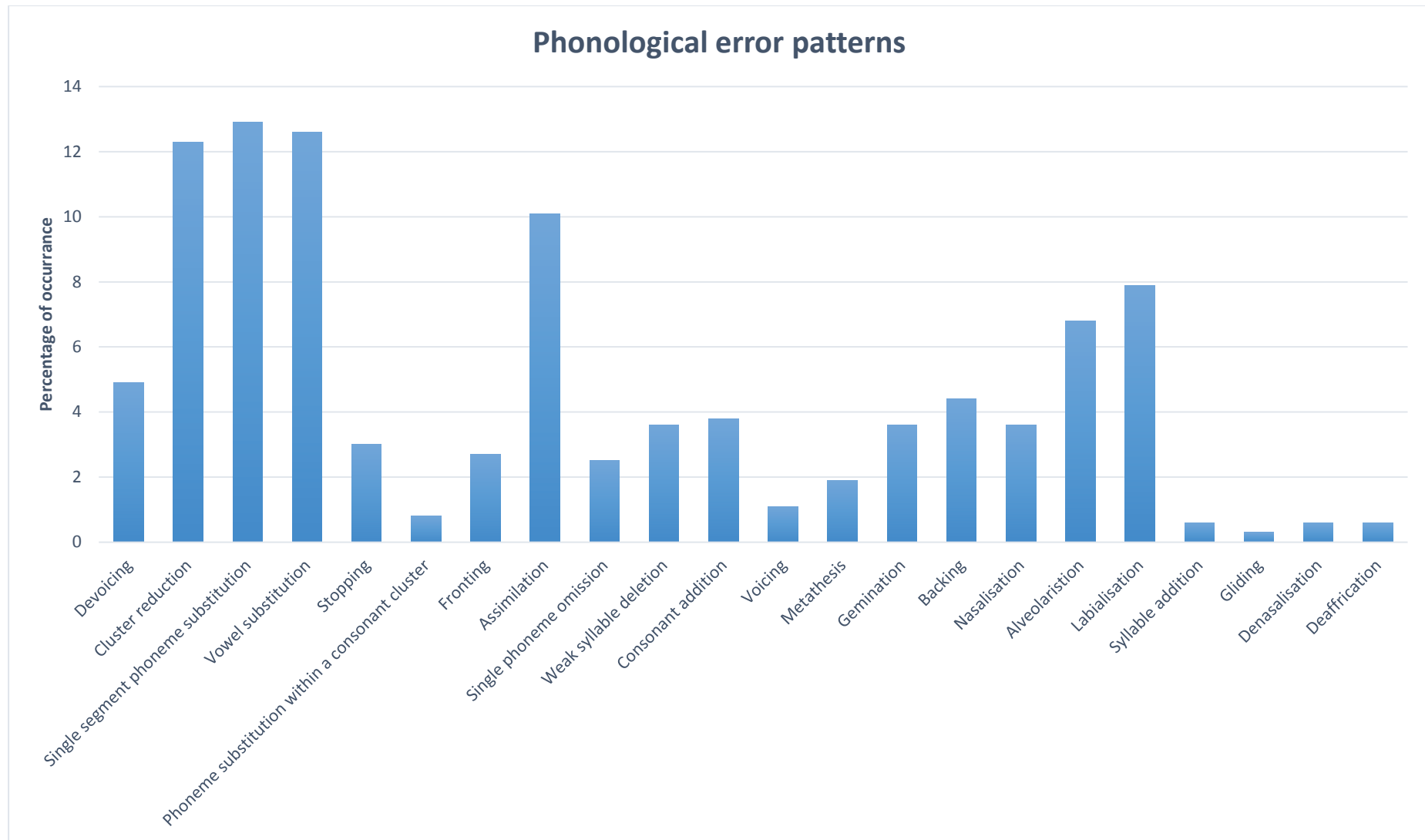


Figure 106 Percentage of occurrence of the phonological errors produced by the clinical group in the eNVRT

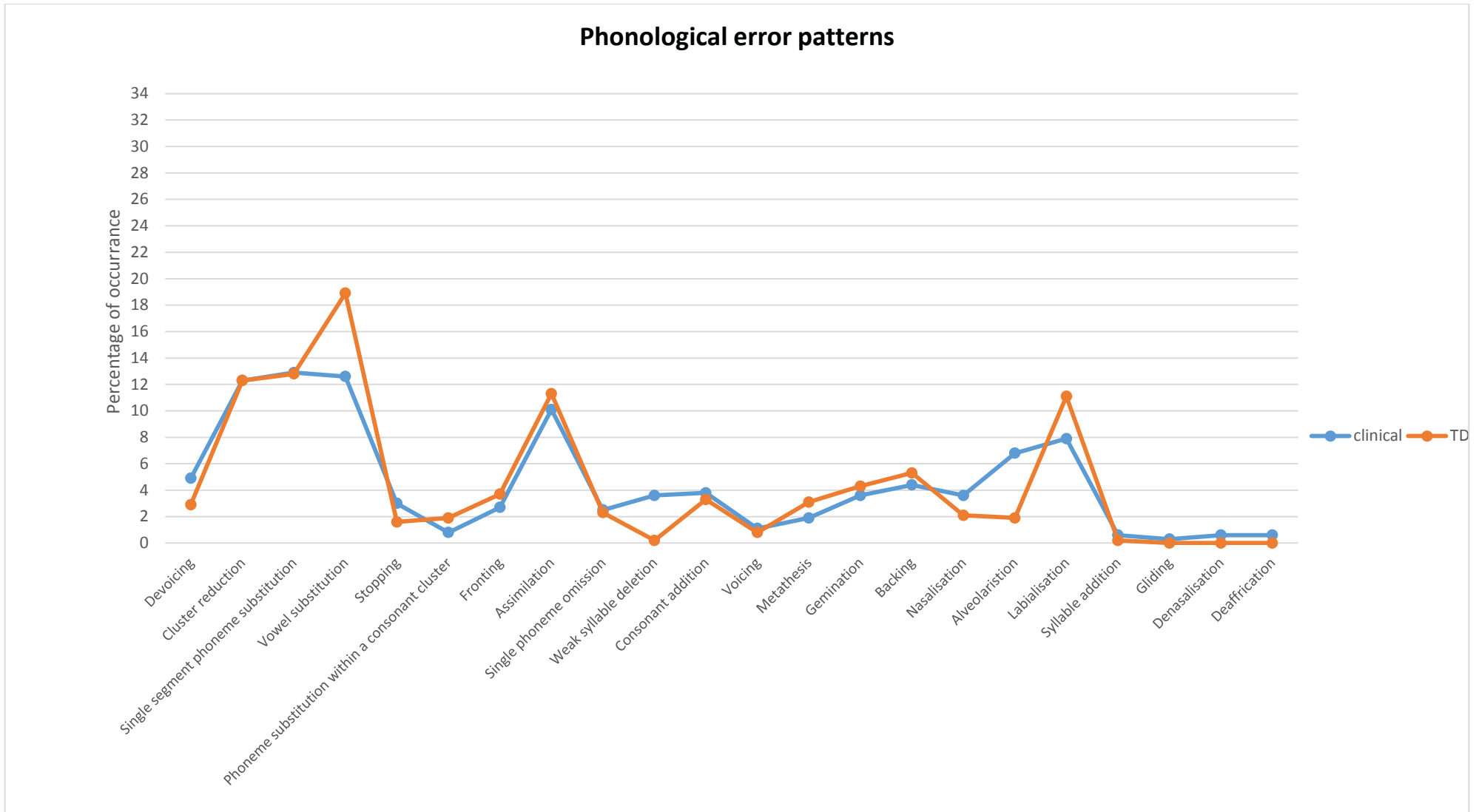


Figure 107 Overlay: Percentage of occurrence of the error patterns produced by both groups in the eNWRT

6.1.3 Acoustic analysis. The target nonwords that were subjected to a high amount of the same error (by both TD and clinical groups) were compared with the ‘mispronounced’ nonword through a visual analysis of the acoustic energy (i.e. their spectrograms). These nonwords comprise /lɪ'rɑntʃ/, /rɛv:ɔfɪjɑ/, and /kærɛ'wat:/ under the Maltese list, and /tʃəmənt/, /prɒ'mɪfɪtəs/, /dʒætə'bædən/, and /krʌkɒdɜ:d/ from the English list:

- Denasalisation within the syllable final consonant cluster. This pattern emerged in both the Maltese and English-based lists, where the difference between the target nonword and child production consisted of an elimination of the [n] within the syllable final consonant cluster in the nonwords /lɪ'rɑntʃ/ versus /lɪ'rɑtʃ/ (Maltese-based), and /tʃəmənt/ versus /tʃəmət/ (English-based). The spectrograms in figures 6.9 and 6.10 illustrate the formant distribution of the target nonwords (left side) and child produced nonwords (right side).

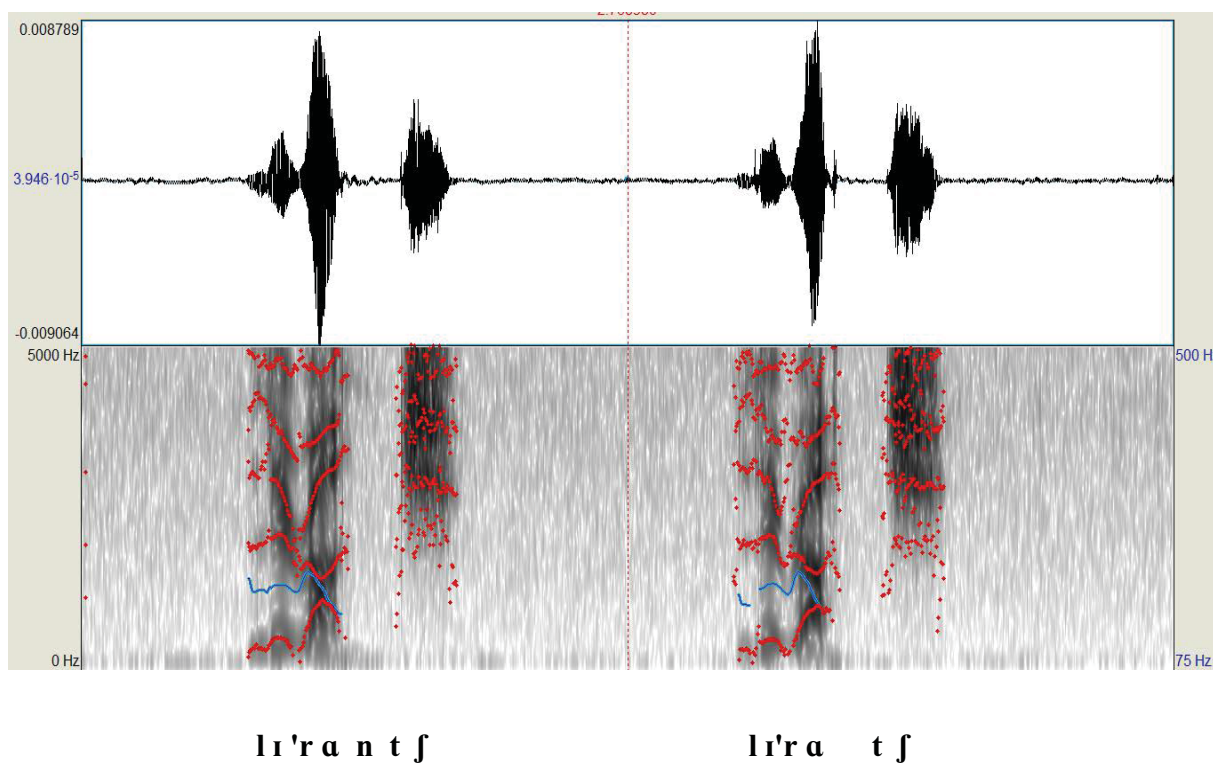


Figure 108 Spectrogram illustrating /lɪ'rɑntʃ/ and /lɪ'rɑtʃ/

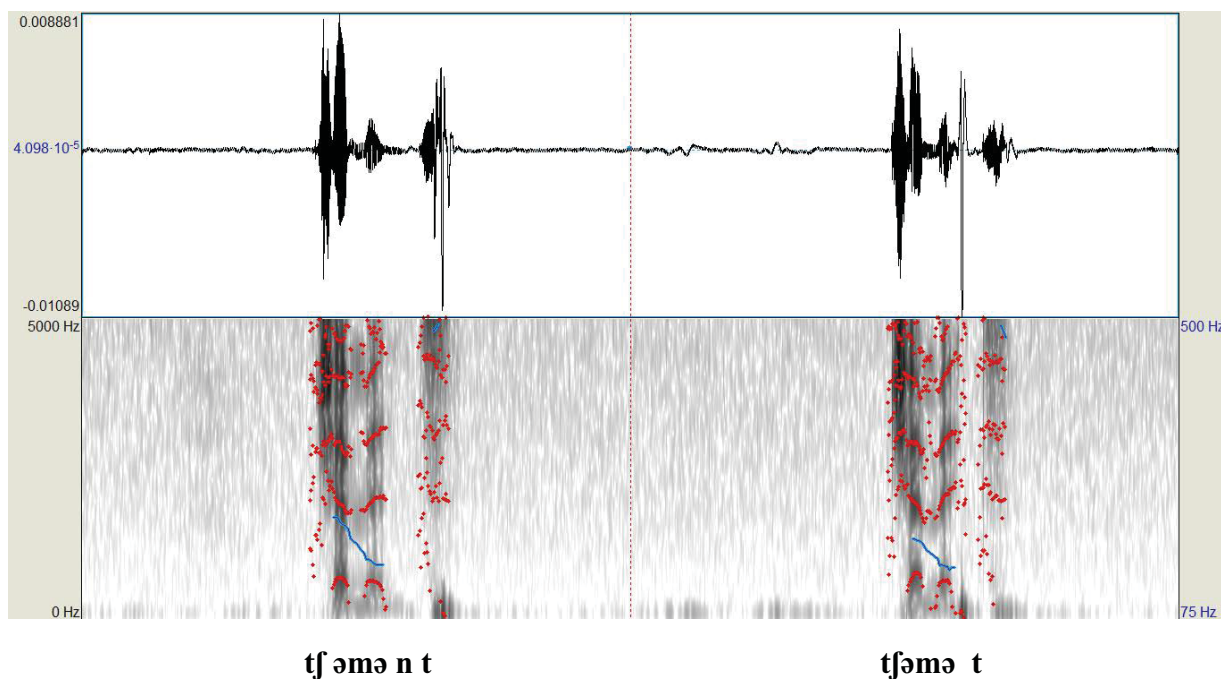


Figure 109 Spectrogram illustrating /tʃəmən t/ and /tʃəmət/

In both figures little difference emerged between the two nonwords demonstrating the low amount of acoustic energy emerging from the nasal sounds.

- Substitution of fricatives by stops in syllable initial approximants and fricatives. The substitution of fricatives by stops occurred frequently in two nonwords: the Maltese-based /kærə'wat:/, in which the labial-velar approximant [w] was substituted with the voiced bilabial plosive [b] (figure 110); and the English-based /prə'mɪfɪtəs/, where the labio-dental voiceless fricative [f] was substituted with the voiceless alveolar plosive [t] (figure 111).

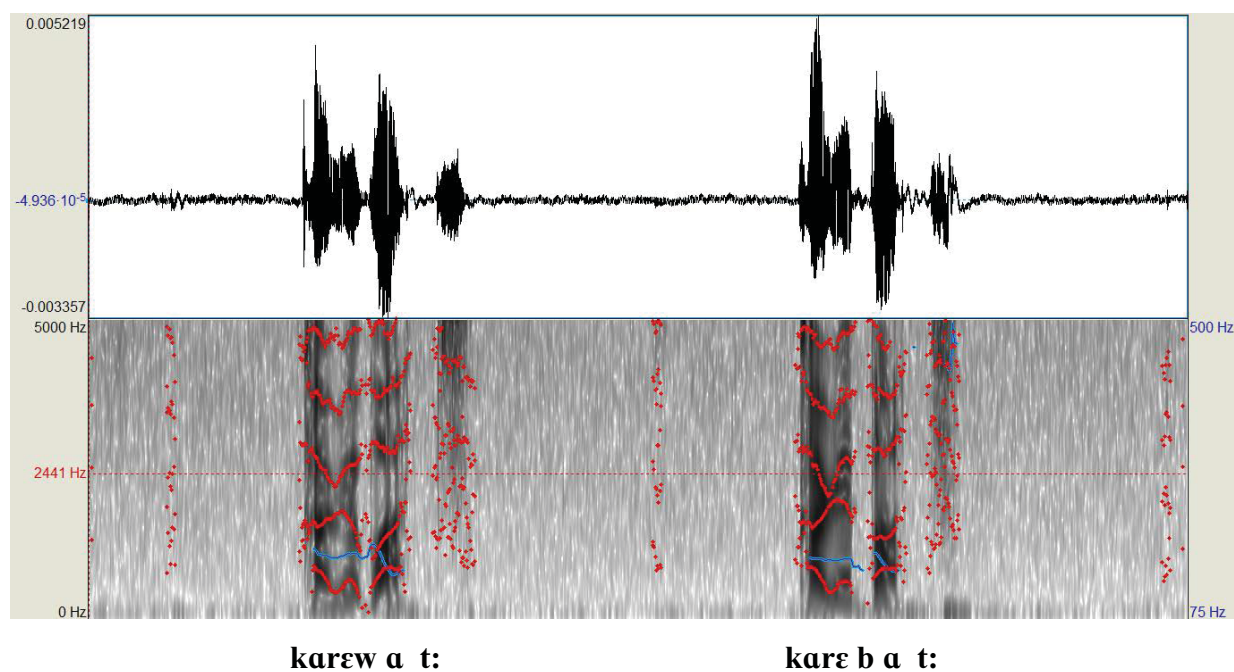


Figure 110 Spectrogram illustrating /karɛ'wat:/ and /karɛ'bat:/

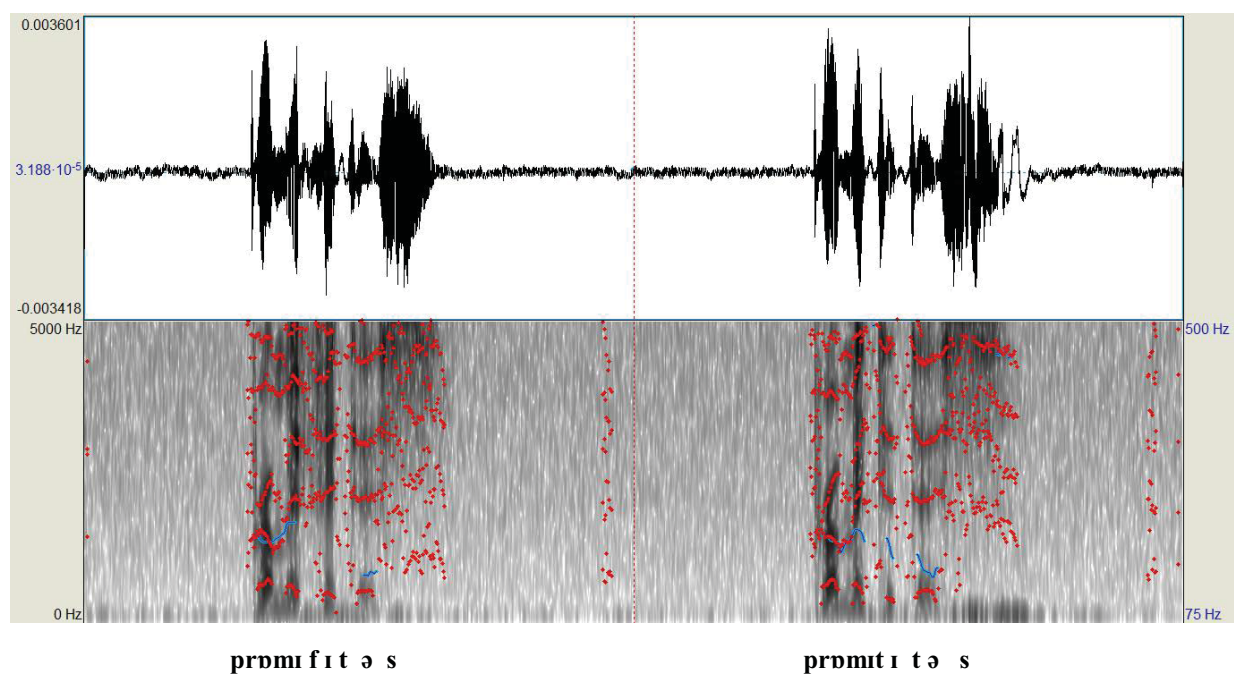


Figure 111 Spectrogram illustrating /prɔ'mɪfɪtəs / and /prɔ'mɪtɪtəs /

- Devoicing of geminate. The spectrograms in figure 112 illustrate the frequent occurrence in devoicing of the geminate [v:] of the target nonword and child production.

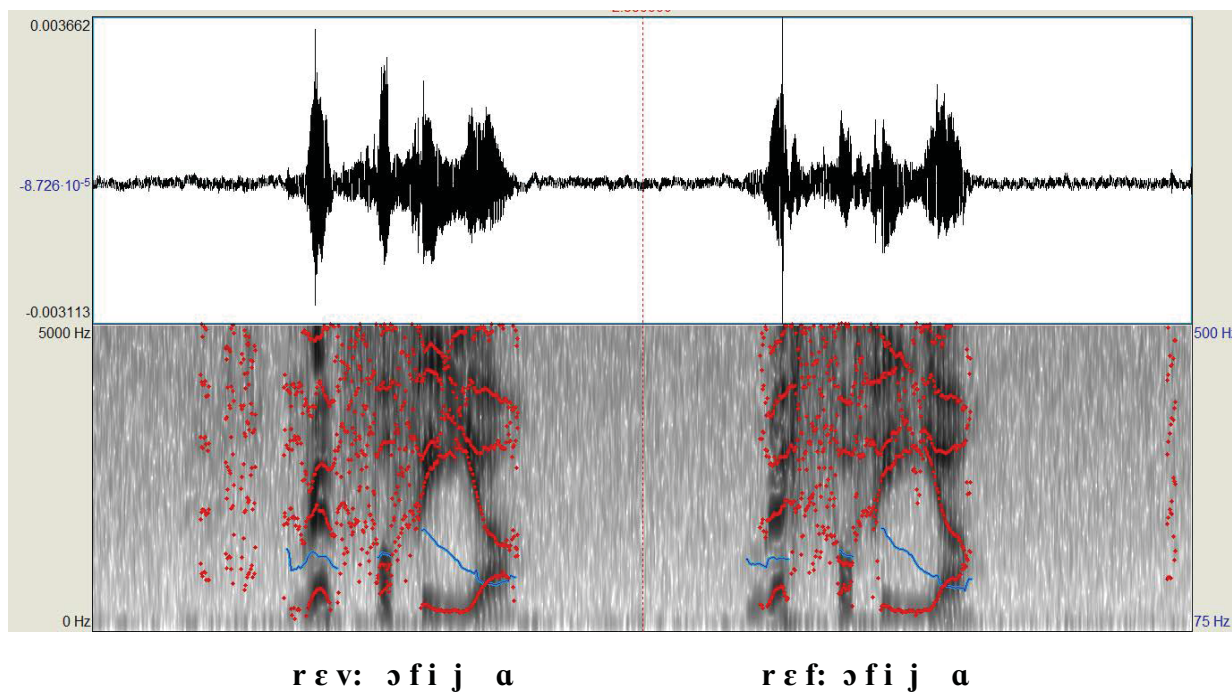


Figure 112 Spectrogram illustrating /rɛv:ɔfiɔ/ and /rɛf:ɔfiɔ/

- Vowel substitutions. The child production of the target nonword /krʌkɔdə:d/ consisted of the frequent substitutions of two vowels, namely [ʌ] to [ɒ] and [ə:] to [ɪ].

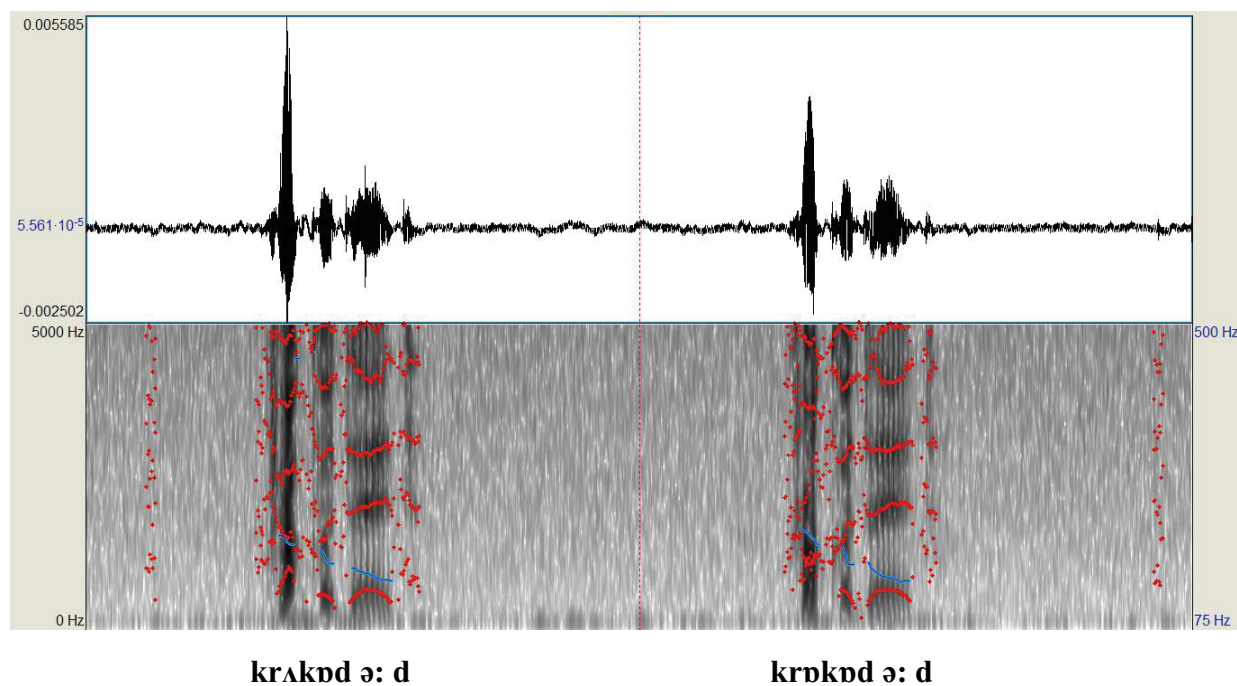


Figure 113 Spectrogram illustrating /krʌkɒd ə: d/ and /krɒkɒd ə: d/

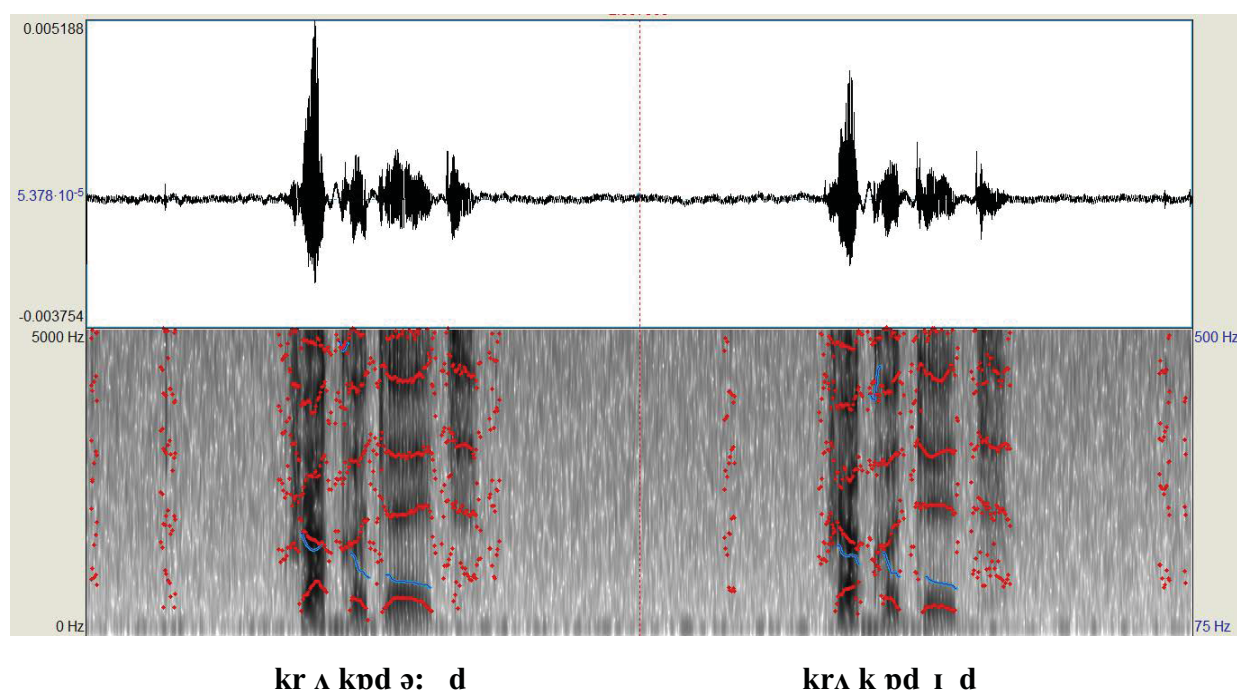


Figure 114 Spectrogram illustrating /krʌkɒd ə: d/ and /krʌkɒd ɪ d/

- Syllable final substitution of /n/ with /r/.

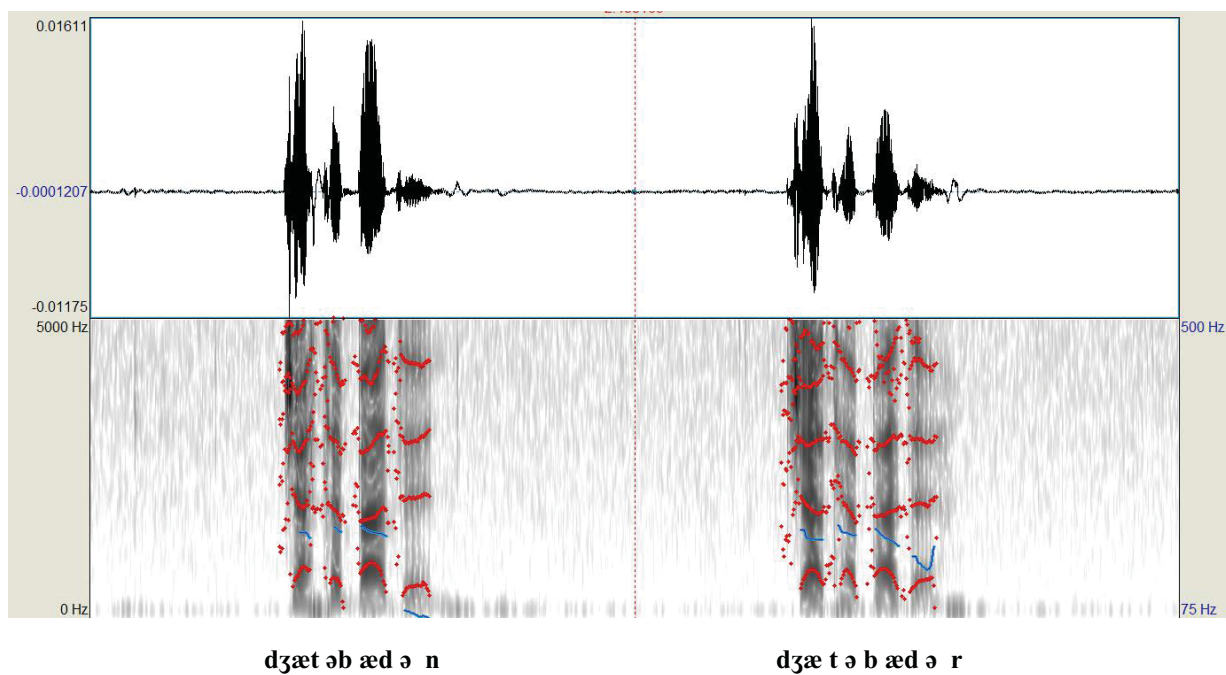


Figure 115 Spectrogram illustrating /dʒætə'bædən/ and /dʒætə'bædər/

6.2 Sentence Imitation Task (SIT)

Throughout this section, a content analysis of the children's responses in the SIT is presented. The inaccurate imitations are presented in terms of: (1) the incomplete imitation

of the sentences (either partial or total), (2) grammatically incorrect imitation, and (3) grammatically correct but inaccurate imitation. These results compare and contrast the sentence repetition of the TD and clinical groups, further divided into the language with which they preferred to execute the task (their primary language (PL)). All the inaccuracies produced by the TD group are explained in tables 126 (Maltese responses) and 127 (English responses) of appendix D. The inaccuracies that emerged from the clinical group are then shown in tables 128 (Maltese responses) and 129 (English responses).

Figure 116 illustrates the percentage of incorrect repetitions produced by the TD and clinical groups in each sentence. The general pattern showed that as the sentences increased in length and complexity, there were more inaccuracies in repetition from both groups. The performance of each group in sentences 1, 3 and 4 were similar. The majority of the children were able to repeat these sentences accurately. A higher percentage of the clinical group tended to repeat sentence 2 incorrectly. In sentences 5 through to 8 the clinical group were found to repeat the sentences with more inaccuracies than the TD group, shown as a substantial gap between the two groups in figure 116. In the last two sentences this gap lessened, due to the fact that all participants (100%) forming the clinical group inaccurately repeated these sentences, as well as a high percentage (>90%) of inaccurate repetitions produced by the TD group.

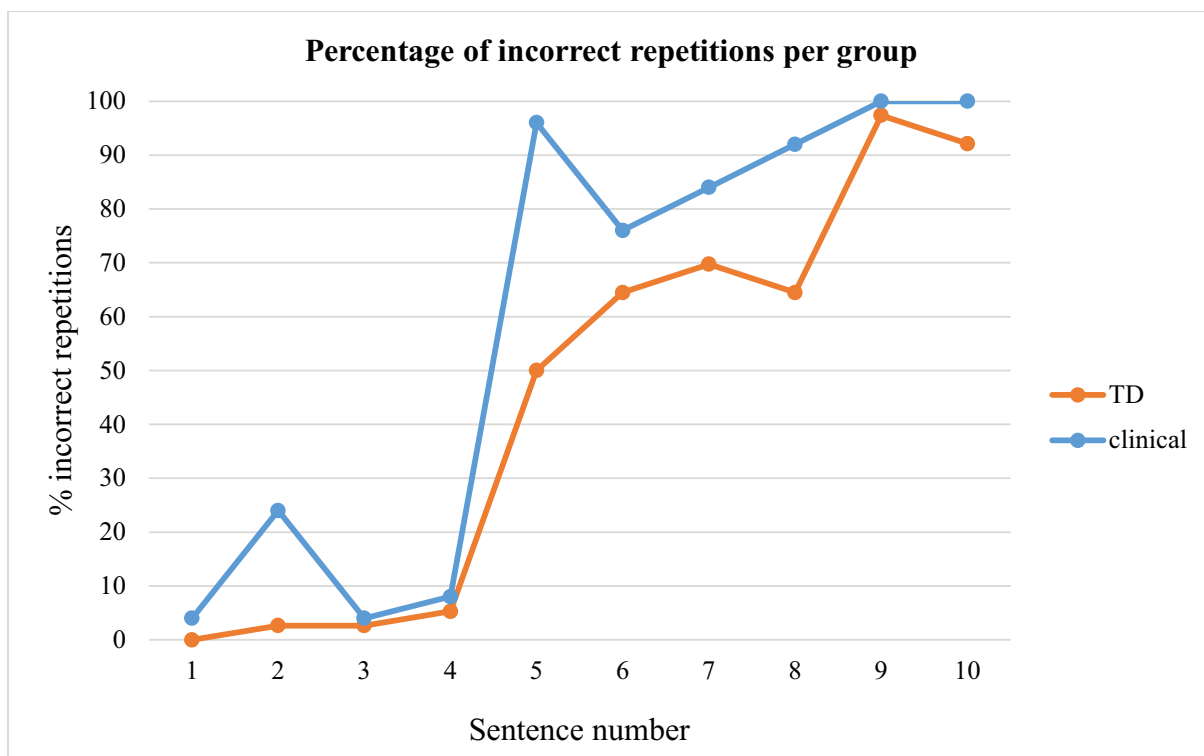


Figure 116 Percentage of incorrect repetitions produced by the TD and clinical groups in each sentence

Figure 117 depicts the percentage of partial or total omissions sentences repeated by the TD and clinical groups in each sentence. Sentences which were repeated with more than half of the words omitted, as well as those that were not repeated at all were included in this analysis. The figure clearly shows that within the TD group there were no instances of complete or partial omissions in sentences 1 to 6, while only a few (between 4 and 11%) emerged in the Maltese sentences 7 to 10. More instances of omissions were found in the clinical group. While all the children were able to complete sentences 1 to 4, more difficulties were evident in the longer sentences. A small percentage of the children (between 4 and 11%) omitted partially or completely sentences 5 to 8. The omissions increased substantially in the final two more complex sentences, clearly showing the gap between the

performance of the TD and clinical groups. The sentences which included omitted text are displayed as blue font in tables 126 to 129 of appendix D.

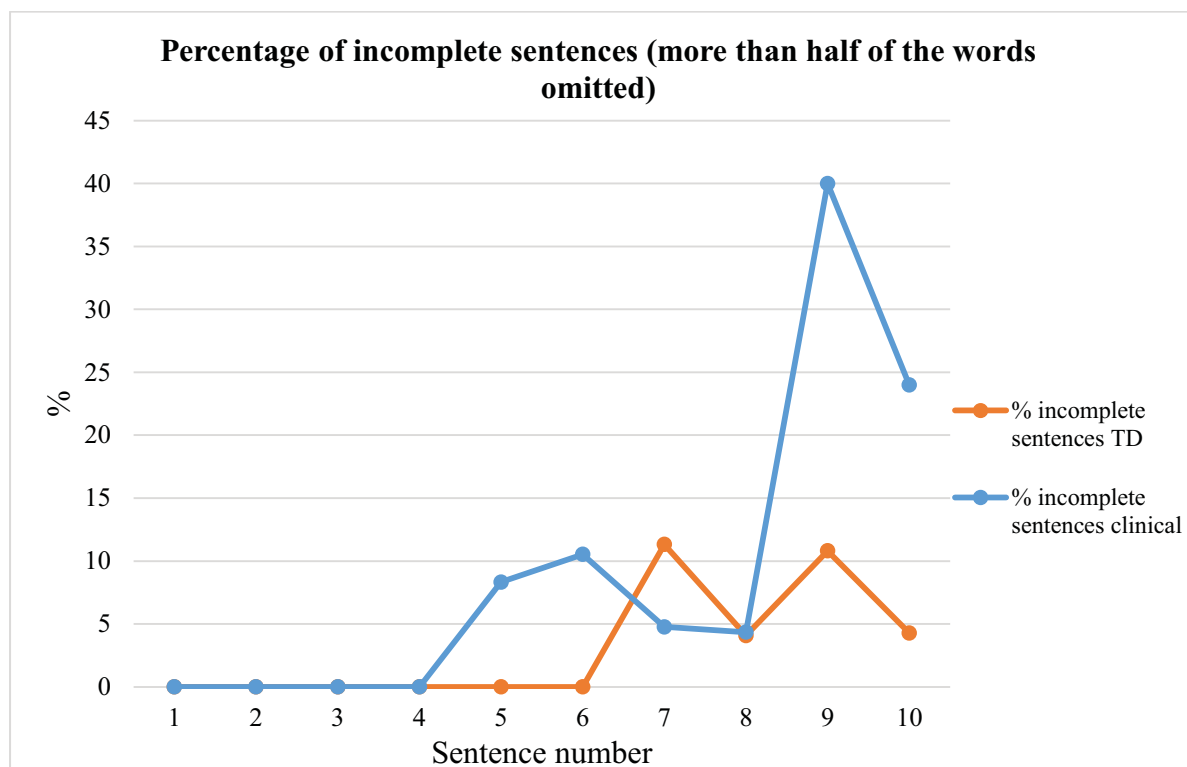


Figure 117 Percentage of incomplete sentences repeated by the TD and clinical groups in each sentence

Figure 118 highlights the percentage of grammatically incorrect sentences repeated by the TD and clinical groups in each sentence. The TD group exhibited a similar pattern to their performance with regard to the omissions in sentences, where the repetition of the first six sentences included no grammatically incorrect responses, followed by a low occurrence of grammatically incorrect responses in the next four sentences. On the other hand, the clinical group produced frequent grammatically incorrect responses across the ten sentences. Out of the ten sentences there were no instances of grammatically incorrect responses in

sentences 1, 3, and 5. All other sentences were subjected to some grammatically incorrect repetitions to some extent, with sentences 4 and 7 being subjected to the most frequent occurrences. The reader is directed to the text displayed as red font in tables 126 to 129 of appendix D to view the grammatically incorrect sentences produced by the participants.

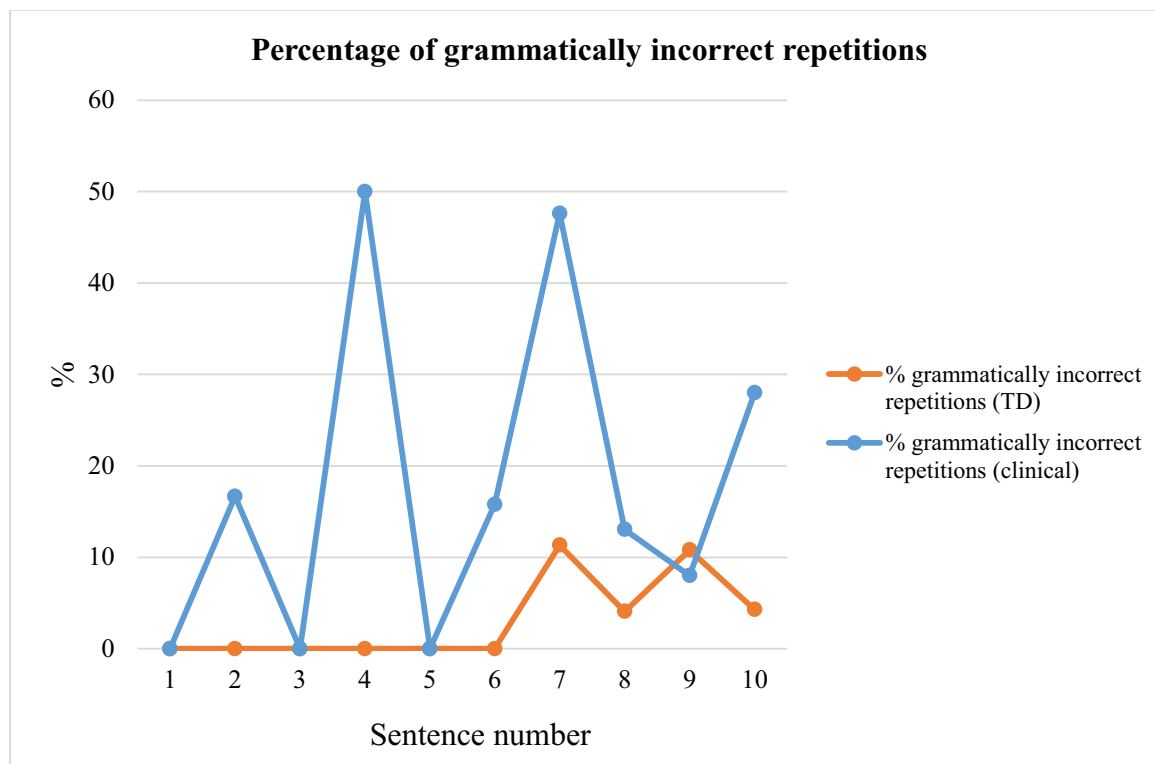


Figure 118 Percentage of grammatically incorrect sentences repeated by the TD and clinical groups in each sentence

Finally, each sentence was analysed for the errors which emerged the Maltese and English language. These mainly included inaccurate but grammatically correct imitations, grammatically correct imitations, and omissions of words within the sentences. This is explained in table 73 below. The analysis was carried out separately for the TD and clinical groups, in which errors occurring in both the Maltese and English repetitions are described.

Table 73

Error analysis of the SIT for the TD and clinical groups

Sentence (number)	Analysis: TD group	Analysis: clinical group
(1) There were a boy and a girl. (Kien hemm tifel u tifla.)	No instances of errors emerged for this group.	There was only one instance (amounting to 4% of this group) of an inaccurate imitation. However the sentence was still grammatically correct.
(2) Mummy was going to take them to the seaside. (Il-mama' kienet ser toħodhom il-baħar.)	A minimal amount (3%) of the children produced an error in this sentence. These incorrect imitations were all grammatically acceptable and were all related to the preposition indicating purpose: 'to' when repeated in English, which was followed by an addition of the verb 'go', and 'ser' when repeated in Maltese. In this case it was replaced with the analogous word 'ħa'.	24% of the responses included inaccuracies in imitation. No common error pattern emerged across and within both PL groups. There was also one instance of a grammatically incorrect repetition within the PL English group.
(3) Mum prepared the sandwiches. (Il-mama' lestiet il-ħobż biż-żejt.)	Only 3% of the children repeated this sentence incorrectly. There were no grammatically incorrect repetitions. Errors included an omission of the article 'il-' ('the') in Maltese and substitutions of the verb 'prepared' in the English repetition.	One incorrect imitation emerged within the PL Maltese responses: the substitution of the verb. This error also emerged in the TD PL English group.
(4) The children put on their swim suits and hat. (It-tfal libsu l-malja u kappell.)	5% of the children incorrectly repeated this sentence. The Maltese SIT productions were all grammatically acceptable and included an omission of the article 'il-' ('the'). The English SIT production included one grammatically acceptable error, consisting of an addition of the possessive pronoun 'their'. A grammatically incorrect repetition also emerged at one instance in which the adverb 'on' was omitted.	8% (two) of the participants repeated this sentence inaccurately. The inaccuracy produced by the PL Maltese participant also occurred in the article 'il-', but unlike the inaccuracies emerging TD group (i.e. an omission), the sentence included an <i>addition</i> of the article 'l-' before the word 'kappell' ('hat'). This sentence production is grammatically correct. The PL English repetition was grammatically incorrect with the omission of 'on'. This was the same inaccuracy that emerged in the TD group.

<p>(5) The children, mum and the dog went in the red car. (<i>It-tfal, il-mama' u Fido daħlu fil-karozza l-ħamra.</i>)</p>	<p>This sentence revealed a marked increase in the number of participants who produced incorrect repetitions – 50%. Interestingly, a common error that was observed in both the Maltese and English sentence repetition was the omission of the adjective ‘red’ (or ‘l-ħamra’). This was omitted in 33.33% of the Maltese responses and 37.5% of the English responses. In addition to this error, other common errors specific to the language of repetition emerged. The PL Maltese children tended to switch the position of ‘<i>It-tfal, il-mama' u Fido</i>’ (‘The children, the mum and Fido’) to produce ‘<i>Il-mama', it-tfal u Fido</i>’ (‘The mum, the children and Fido’). This emerged 43.33% of the times. A common error emerging in the PL English participants was the addition of ‘the’ before the word ‘mum’, which emerged in 37.5% of the participants.</p>	<p>Similar to the TD group, there also was a substantial increase in inaccurate repetition. 96% of the participants inaccurately repeated this sentence, where in comparison with the 50% errors from the TD group, nearly all participants in the clinical group showed difficulties repeating this sentence. The most common inaccuracy (33.33%) in the PL English was the omission of ‘red’ (similar to the TD participants). This only emerged in 10.53% of the PL Maltese children. The position-switching of the persons mentioned in the sentence was also common in both PL Maltese (21.05%) and English (25%) groups. Both groups also tended to leave out ‘the children’ (<i>‘it-tfal’</i>). Unlike the TD participants, some children forming part of the clinical group (10.6% of the PL Maltese children) were unable to complete the sentence.</p>
<p>(6) As soon as they arrived Xandru and Maria went running to swim. (<i>Kif waslu Xandru u Marija telqu jiġru biex jgħumu.</i>)</p>	<p>Being longer than the previous sentence, the repetition of this sentence was characterised by an even higher percentage of incorrect responses by the participants. More than half of the children (64%) responded with an inaccurate repetition to some degree. 5.8% of the PL Maltese and 14.8% of the PL English repetitions were grammatically incorrect. Irrespective of the PL, it emerged that the most frequent error was in the verb phrase ‘went running’ (<i>‘marru jiġru’</i>) in which the word ‘running’ (<i>‘jiġru’</i>) was omitted. In addition, within the Maltese sentence repetition, the verb ‘telqu’ (‘went’) was frequently substituted with the analogous term ‘marru’. This was not the only word which the children tended to substitute. The term ‘kif’ (‘as soon as’) was also commonly substituted with the analogous term ‘x’hin’. Another frequent pattern which surfaced</p>	<p>In comparison with the previous sentence, less participants in this group produced inaccuracies in the repetition of this sentence (76%). However, there was still a higher percentage than the TD group. 15.4% of the PL Maltese and 11.11% of the PL English participants produced grammatically incorrect repetitions. Similar to the TD group, a high percentage of the clinical group produced inaccuracies in the verb phrase. 33.33% of the PL English group omitted ‘running’. 23.08% of the PL Maltese group commonly tended to substitute ‘telqu’ with ‘marru’ and with other verbs (in a further 11.54% of the responses). There was also a tendency to omit ‘jiġru biex’ (running to). Finally, it emerged that 33.33% of the PL English children in this group tended to shorten the phrase ‘as soon as’ to ‘when’. This substitution did not emerge in</p>

	<p>especially in the PL English group, is that following the word ‘went’ the children tended to explain the rest of the sentence in their own words. Although this was often grammatically and semantically correct, it was considered erroneous in terms of the task requirements. Finally, a higher percentage of the grammatically incorrect responses emerged from the PL English group (14.8%) in comparison with the PL Maltese group (5.8%).</p>	<p>the TD group.</p>
<p>(7) Xandru stayed filling the buckets with sand and turning them upside down. (Xandru qagħad jimla il-bramel bir-ramel u jaqlibhom rashom ‘l isfel.)</p>	<p>70% of the participants inaccurately repeated this sentence. Of which, 8.4% of the sentences produced by the PL Maltese group and 11.6% by the PL English group were grammatically incorrect. Within this sentence, incomplete imitation also occurred (in 2.8% of the PL Maltese repetitions and 8.7% of the PL English repetitions). In both groups, the vast majority of errors arose in the verbs. In the verb phrase ‘stayed filling’ / ‘qagħad jimla’ was substituted in 35% of the instances within the PL English group (in which the majority of the participants substituted it with ‘kept filling’) and 33.5% in the PL Maltese group (where ‘qagħad’ (‘stayed’) was frequently substituted with ‘beda’ (‘started’)). The verb phrase ‘turning them’ / ‘jaqlibhom’ was subjected to an even higher percentage of substitutions: 38.1% of the inaccuracies produced by the PL English group and 55.9% of the Maltese group. The highest percentage error in the PL English group was the substitution of the word ‘turning’ with ‘putting’. The majority of the Maltese group tended to add ‘qagħad’ (‘stayed’) before ‘jaqlibhom’.</p>	<p>84% of this group produced errors when repeating this sentence. The repetitions were characterised by a much higher percentage of grammatically incorrect responses when compared with the TD group: 33.2% in the PL Maltese speakers and 49.8% of the PL English speakers. The most common errors emerged in the verb phrase ‘jaqlibhom’ (‘turning them’) by PL Maltese group, where it was substituted with other verbs in 58.1% of the responses. The percentage of occurrence for this inaccuracy is similar to the TD PL Maltese group. Amongst the PL English group the most common inaccuracies (amounting to 50%) occurred in the verb phrase ‘stayed filling’. Most commonly, it was substituted with ‘was filling’.</p>
<p>(8) The children had</p>	<p>The participants performed slightly better in repeating</p>	<p>Nearly all participants in this group inaccurately</p>

<p>forgotten the dog and tried to look for him with Marija. (It-tfal kienu nsew il-kelb u pruvaw ifittxuh ma' Marija.)</p>	<p>this sentence when compared with the previous one, with 64% producing some error. Both groups were found to incorrectly repeat the past perfect verb tense 'had forgotten' / 'kienu nsew'. 40.7% of the PL English group replaced it with the past tense 'forgot'. 14.8% of this group also substituted it with the grammatically incorrect phrase 'had forgot'. The same substitution emerged in the PL Maltese group, where it was replaced with the past tense 'insew' 66.7% of the times.</p>	<p>repeated this sentence. The error patterns were similar to the TD group, showing substitutions in the verb phrase 'had forgotten' / 'kienu nsew'. 60% of the errors produced by the PL Maltese group included the omission of 'kienu' ('had'). Similarly 47.1% of the PL English utterances replaced 'had forgotten' with 'forgot'. No instances of the grammatically incorrect 'had forgot' emerged within this group. However, grammatically incorrect responses were recorded in both Maltese (10%) and English (5.9%) PL groups.</p>
<p>(9) Mum had to jump in the water to fetch him since Xandru and Maria were not allowed to swim so far away. (Il-mama kellha taqbeż tgħum għalih għax Xandru u Marija ma kellhomx permess jgħumu daqsekk 'il barra.)</p>	<p>Being the longest out of the 10 sentences, this sentence could be considered as the most difficult one to imitate. Nearly all the participants in this group (97%) repeated this sentence with some inaccuracy. 6.3% of the PL Maltese group and 3.3% of the PL English group produced grammatically incorrect substitutions. The errors were varied substantially in both groups. However, a common error pattern did emerge in the PL Maltese group: 21.6% of the children tended to leave out the word 'tgħum' ('swim'). A possible reason for this could be that the omission of this word would not change the meaning of this sentence. This suggests that 'tgħum' can be considered an extra word. Without it, one would still understand that <i>mum is jumping in the sea and swimming for the dog</i>. Another substitution commonly observed in the PL Maltese group was the change of the verb tense 'kellha taqbeż' ('had to jump') into 'qabżet' ('jumped'). This emerged in 9.9% of the children's utterances. There were also a number of substitutions towards the end of the sentence 'ma kellhomx permess jgħumu daqsekk 'il barra' ('were not allowed to swim so far away').</p>	<p>All participants in this group repeated this sentence with inaccuracies. Only 2.9% of the PL Maltese group produced grammatically incorrect substitutions. Some of the commonly emerged errors were very similar to the TD group, such as the omission of 'tgħum' (most common error; 22.9%), the use of 'qabżet' in the place of 'kellha taqbeż' (8.6% of the errors), the omission of the final phrase in the sentence 'daqsekk 'il barra' ('so far away') and the insertion of 'il- / ġol-baħar' ('in the sea'). 6.7% of the PL English clinical group produced grammatically incorrect substitutions. A common error pattern that emerged was the substitution of 'had to jump' with the term 'jumped', which made up 20% of the inaccuracies. 13% of this group also shortened 'had to jump' with 'went'. Unlike the TD group, there weren't many instances of inaccuracies within the phrase 'to fetch him'.</p>

	<p>The verb <i>'jgħumu'</i> ('swim') was substituted with another verb 15.3% of the error types. The following (<i>'daqsekk 'il barra'</i>) was also subjected to substitutions; the most common one being the omission of <i>'daqsekk'</i> ('so far') (9% of the error types).</p> <p>Unlike the repetitions of the PL Maltese group, the responses of the PL English group did not bring out a very commonly occurring substitution. What <i>did</i> emerge was the substitution of the verb 'fetch' with other verbs, such as 'catch', 'get' and 'save'. This occurred in 12.1% of the error types. The phrase 'to fetch him' was also omitted in 8.8% of the participants' responses, possibly suggesting that these participants might not be too familiar with the term 'fetch'. Other more common substitutions included the term 'since' with the analogous term 'because' or 'cause'. Some participants also substituted the phrase 'were not allowed' with 'couldn't'. Similarly to the PL Maltese group, some of the PL English participants also substituted 'had to jump' with 'jumped'. This emerged in 7.7% of the substitutions.</p>	
<p>(10) The children started clapping as soon as mum arrived near them with Fido in her hands. (It-tfal bdew iċapċpu kif il-mama' waslet ħdejjhom b'Fido f'idejha.)</p>	<p>92% of the participants repeated this sentence with inaccuracies. In both groups, 10% of the repetitions were grammatically incorrect, while 2.8% of the utterances produced by the PL Maltese group were incomplete. The most common error pattern was the same for both groups. This was the omission of the words 'near them' (24.5%) and the Maltese equivalent <i>'ħdejjhom'</i> (18.8%). The next most frequent error pattern was also common to both groups, and comprised the substitution of 'as soon as' (17%) and</p>	<p>All participants within this group inaccurately repeated this sentence. When compared with the TD participants, this group produced a higher amount of grammatically incorrect repetitions (PL Maltese – 16.8%; PL English – 27.9%). A higher number of children within this group were also unable to complete the sentence, producing only part repetitions (PL Maltese – 8.4%; PL English – 16.8%). Other than these inaccuracies, some of the errors exhibited by this group were similar to the TD participants, with the</p>

	<p>the Maltese equivalent '<i>kif</i>' (23.2%) with analogous terms. Errors specific to each group also emerged. 13.2% of the utterances produced by the PL English group involved the substitution of the words 'arrived near them' with 'came'. On the other hand, 10.1% of the Maltese group tended to omit the last word '<i>f'idejha</i>' ('in her hands').</p>	<p>omission of 'near them' (16.7%) and the Maltese equivalent '<i>ħdejhom</i>' (25%) emerging the most. One error was common to both PL clinical groups: Some tended to shorten the verb phrase 'started clapping' and the Maltese equivalent '<i>bdew iċapċpu</i>' into the simple past tense 'clapped' (16.7%) and '<i>ċapċpu</i>' (12.5%) respectively.</p>
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6.3 Discussion – Research question 5: What error patterns emerge in the typically developing children and those with reported listening difficulties on the tests of language processing?

The language processing abilities in children with reported listening difficulties and suspected APD have been reported in numerous studies (as was reviewed in section 2.12.1), probably due to the frequent reported co-morbidity between listening or auditory processing skills and language and reading abilities (Chermak and Musiek, 1997; Ferguson et al., 2011; Sharma et al., 2009; Weber-fox et al., 2010). Similarly to this research, some studies have specifically investigated language abilities through nonword and sentence repetition. Ferguson et al.,'s (2011) outcome was of a discrepancy in performance between mainstream school children and those diagnosed with APD or DLD, but no difference in performance between the two clinical groups. The authors concluded that the two groups tend to display analogous profiles of language processing. Other studies produced similar outcomes. Dawes and Bishop (2011) reported no difference in the performance of children with APD and dyslexia on a variety of assessments, including nonword and sentence repetition. Similarly, Tabone et al.'s (2016) study on Maltese children found that the TD participants obtained significantly better results than the children with a diagnosed DLD and LitD on the nonword and sentence repetition tests. What studies do not frequently report, is the type of errors that emerge in these populations reported to have listening difficulties, and who are diagnosed as having either APD, DLD, LitD or ADHD. It was therefore of interest in this research to try to obtain this information. The properties of Maltese and English were captured through gathering preliminary data for error patterns occurring in the Maltese TD and clinical groups.

6.3.1 Error patterns emerging in the NWRs. As was mentioned in sections 6.1.1 and 6.1.2, the syllable length of the nonwords did not affect the mean percentage error in the TD group for both Maltese- and English-based subtests. These same tests had been previously administered to younger Maltese children (5-year olds) than the ones in this research (Calleja & Grech, 2014), with contrasting results. The authors report significantly more errors with increasing syllable length in both subtests. The contrast in findings could probably be due to the effect of age, and hence more developed language abilities, on the performance of the NWRs. These outcomes seem to be in line with some previous studies. Roy and Chiat (2004) found that young children, aged between 2;00 and 3;11 years produced more errors on three-syllable nonwords than two-syllable nonwords. Dispaldro, Deevy, Altoe', Benelli and Leonard's (2011) results from Italian monolingual children aged between 3;00 and 4;00 years were in agreement. The authors report decreased production accuracy in the longer nonwords. Interestingly, the same study did not find a congruent outcome in their monolingual English speaking participants. The authors convey no emergence of a word length effect. Girbau and Schwartz (2007) report data from older children speaking Spanish. Similar to this research, their data show that the TD children performed similarly in terms of the mean nonwords correct across 2-, 3-, and 4-syllables. Research on simultaneous French-English bilingual children with unequal exposure to each language (Thordardottir & Brandeker, 2012) has also found syllable length not to affect their NWR performance. However, varying results have also been reported. Marton and Schwartz (2003) found that the accuracy of English-speaking children aged between 7;00 and 10;00 decreased as the syllable-length increased.

All participants produced most inaccuracies in the consonant clusters and (to a lesser extent) the consonant sequences within the nonwords. A similar pattern was also observed in the younger Maltese children (Calleja & Grech, 2014), where the authors report more errors

in the consonant clusters and consonant sequences than in the single consonants of the Maltese and English NWRTs. Nonetheless, this outcome does not always hold across language-based nonword tests. Archibald and Gathercole (2006) analysed the NWRT responses in English speaking children using the Children's Test of Nonword Repetition (CNRep) (Gathercole & Baddeley, 1996). They show that their TD group obtained similar mean percentage phoneme correct scores for nonwords incorporating single consonants and consonantal clusters. Perhaps the difference in performance across different tests might stem from the type of nonwords used. It is known that the phoneme sequences in the nonwords of the CNRep were all chosen to follow the English phonotactic rules (Gathercole, Willis, Baddeley & Emslie, 1994) and include numerous real morphemes of English (Chiat, 2015). On the other hand, the nonwords forming the Maltese and English NWRTs were chosen to contain both high and low lexicality nonwords (as was explained in section 3.6.2) and contain few morphemes of each target language.

A higher percentage error was expectedly noted in the clinical group across both language-based nonwords (figures 6.1 and 6.5). The bar graphs demonstrate that although the clinical group performed worse overall than the TD children (more errors across all syllable lengths and segmental complexities) the two groups seem to produce a similar error pattern. This occurrence has already been reported (Marton & Schwartz, 2003). In both NWRT subtests the syllable length did not affect substantially the repetition performance, but more errors emerged in the more segmentally complex nonwords involving consonant clusters and sequences.

Much research focusing on NWRT error analysis has shown interest on the performance of children with language and reading difficulties in this task. Considering the reported similar behavioural profiles of children with a diagnosis of APD, DLD, and LitD, such studies will be considered in this discussion. While findings on the outcome of NWR in

TD children and those with a language / reading impairment vary somewhat across studies (Chiat, 2015), the reports seem to be consistent. Children with these impairments tend to produce more errors in the nonwords of increased segmental complexity (e.g. Archibald & Gathercole, 2006; Gallon, Harris & van der Lely, 2007; Leclercq, Maillart & Majerus, 2013; Marshall & van der Lely, 2009) and longer syllable length (e.g. Archibald & Gathercole, 2006; Dollaghan & Campbell, 1998; Graf-Estes, Evans & Else-Quest, 2007; Jones et al., 2010; Munson, Kurtz & Windsor, 2005; Weismer et al., 2000). The findings of this study are consistent with the already-established body of research, suggesting that the same difficulties are also evident in bilingual Maltese children.

Despite the extensive research addressing NWRT in TD and clinical populations across languages, perhaps less attention has been given to the error analysis underlying the scores obtained by each group on this task. This research found that in both NWRTs, a higher percentage exhibited by the two groups were structure preserving (mNWRT - 68.8% and 63.6%; eNWRT – 78.8% and 75.3% for TD and clinical groups, respectively). A similar finding emerged in Riches, Loucas, Baird, Charman and Simonoff (2010), who found that 60% of the errors produced by adolescents with DLD as well as the controls were structure preserving. The outcome of all the children in this study producing more structure changing errors in the Maltese NWRT (despite the fact that the majority used Maltese as their primary language) is perhaps not surprising. Maltese phonotactic rules allow a vast amount of possible cluster combinations, which in turn increases the probability of words containing more complex syllabic structures (Xuereb, 2009).

The highest error pattern percentage in the mNWRT was ‘cluster reduction’. However, as already explained in section 6.1.1, this is most probably due to the high occurrence of syllable final cluster reduction in the nonword /lɪˈrɑntʃ/ to /lɪˈrɑtʃ/. The spectrogram in figure 108 shows little difference between the two nonwords suggesting low

amount of acoustic energy emerging from the nasal sound. This ‘anticipatory denasalisation’, where the end parts of the nasal sound are denasalised in expectation of the oral voiceless obstruent, has already been documented (Ohala, n.d.; Ohala & Ohala, 1993). A similar conclusion could be drawn for the high cluster reduction occurrence in the English subtest for the nonword nonword /tʃəmənt/, which was often reduced to /tʃəmət/ (see figure 109). Other high occurrences of errors in specific nonwords have been identified and reported in section 6.1.3 (acoustic analysis):

- Substitution of fricatives by stops in syllable initial (figures 110 and 111) - On analysing the substitution of /w/ with /b/ in the nonword /kærə'wat:/ it is evident that, despite the variation in manner of articulation, there are similarities in the sounds [w] and [b]: both are voiced and produced at the same place of articulation. This might have caused an uncertainty of the sound perception in the formant transitions. However, the spectrogram in figure 112 does demonstrate less acoustic energy in the production of [w] and [b] when compared with the preceding and following vowels. The difference between the two sounds as highlighted in the spectrogram is that [w] is characterised by formants unlike [b].

In the English-based nonword /prɒ'mɪfɪtəs/, the /f/ was frequently substituted by /t/. While a possible reason for the frequent occurrence of stopping [f] might be due to consonant harmony of [t], it also cannot be excluded that [f], being a voiceless fricative of low turbulence and acoustic energy (as shown in the spectrogram of figure 111), could be perceived as a voiceless plosive [t] within a longer nonword.

- Devoicing of geminate /v:/ in the nonword /rev:ɔfija/ - The difference between the voiced and voiceless fricatives [v] and [f] should be evident through a visible voice bar (dark band in the low frequencies – about 400Hz) for [v] on a spectrogram (Hayward, 2014). This difference is not evident in the spectrogram of the two nonwords (figure 112)

as read by the same reader of the NWRs in the assessment battery, suggesting the possible reason for the frequent substitution.

- Vowel substitution of [ʌ] to [ɒ] and [ə:] to [ɪ] in the nonword /krʌkɒdɛ:d/ - While all vowels are characterised by their own frequency specific formant bars which should lead to differences in their perception, the possibility of the frequent substitution occurrence could lie in the children thinking of a specific real word similar to the nonword (i.e. ‘crocodile’ /krɒkɒdaɪl/), resulting in the [ʌ] / [ɒ] substitution (as illustrated in figure 113). The frequent [ə:] / [ɪ] substitution (figure 114) could be attributed to the fact that [ə] is not present in the Maltese phonetic inventory. Since most participants spoke Maltese as their PL this sound might not be perceived accurately as it is. Furthermore, there have been found many dialectal variations in the vowels produced by Maltese speakers of Maltese and English. This diversity is perceived as a range of normality (Borg & Azzopardi-Alexander, 1997).
- Syllable final substitution of /n/ with /r/ in the nonword /dʒætəbædən/ - When comparing the two nonword variants on the spectrogram (figure 115) it is evident that although the [r] is characterised by faint formants, both [n] and [r] at the end of the word show little energy when read by this speaker. This might be the reason for the frequent substitutions between the sounds.

The overlay illustrations in figures 103 and 107 clearly demonstrate that the error pattern distribution of the two groups for each subtest is similar, irrespective of the higher percentage error produced by the clinical group. This means that in general, if for example there was a high occurrence of vowel and consonant substitutions (compared with other error patterns) in the TD group, there was also this high occurrence in the clinical group. The underlying cause of the augmented difficulties exhibited by children with language

difficulties seems to be debatable. Early studies point to NWRs extracting abilities of phonological short-term memory (Gathercole & Baddeley, 1990; Gathercole et al., 1992), but more recent studies have revealed the significant relationship between linguistic knowledge and NWR performance (Coady & Aslin, 2004; Messer, Leseman, Boom, & Mayo, 2010).

6.3.2 Errors emerging in the SIT. Sentence imitation tasks have long been used in screening assessments, for language impairment and general abilities across various languages (Stokes, Wong, Leonard & Fletcher, 2006). It has been suggested that the underlying mechanisms of sentence imitation are verbal working memory⁶⁸, psycholinguistic skills, or a possibly a combination of both (Hanson & Bowey, 1994; Stokes et al., 2006). Findings from previous studies seem to point to a combination, in which processing and storage are simultaneously required (Marton, Schwartz, Farkas, & Katsnelson, 2006).

Numerous studies have demonstrated links between measures of verbal short-term memory and vocabulary (e.g. Adams, Bourke, & Willis, 1999; Archibald & Gathercole, 2006; Avons, Wragg, Cupples, & Lovegrave, 1998; Montgomery, Magimairaj & Finney, 2010). Hanson and Bowey (1994) specifically show strong correlations between SI and assessments of verbal working memory as well as language proficiency. This link has also been found in the local paediatric population (Grech, Franklin & Dodd, 2011) and is further supported by Botting and Conti-Ramsden (2001), whose findings suggest that verbal ability and verbal short term memory are closely linked, both in terms of phonological output and the more complex language skills.

As was mentioned in chapter 3, the SIT in Malta (Grech, Franklin & Dodd, 2011) has been standardised on children up to 5 years of age, with some additional data obtained on the

⁶⁸ The term 'verbal working memory' has been used to refer to the temporary storage and manipulation of verbal information (Baddeley, 1986).

Maltese version in children aged between 8 and 11 years. Obtaining further data on a different age and PL group aids in adding on the already available data for this population.

The first outcome that emerged from these data is that as the sentence got longer and more complex, the number of incorrect and incomplete repetitions increased in both groups. Figure 117 illustrates the percentage of incomplete sentences when more than half of the words were omitted. This result shows a general pattern of more omissions from the clinical group, especially in the longer more complex sentences. Considering the influence that working memory has in executing a SI task, this outcome might not be surprising. In fact, similar findings have already surfaced in other studies involving TD individuals (Bohannon III, 1975; Willis & Gathercole, 2001), as well as various clinical groups such as those with DLD (Seeff-Gabriel, Chiat & Dodd, 2010) and intellectual impairments (Marcell, Ridgeway, Sewell & Whelan, 1995). However, the cause of these inaccuracies might not be due primarily to the sentence length. Studies comparing the effect of sentence length and linguistic complexity on the performance of sentence imitation conclude that it is the complexity that has the greatest impact. This varied across languages. In English SI, it was found that syntactic complexity affected performance (Marton & Schwartz, 2003). On the other hand, morphological complexity affected performance in the Hungarian language (Marton et al., 2006). These results are of interest to this study. In light of these previous findings, syntactic complexity would surely be expected to have an effect on the performance of SI in the English responses. On the other hand, the Maltese SI could have been affected by the morphological complexity, since similar to Hungarian, the Maltese language is known to comprise a morphologically complex system (Camilleri, 2012). While it is beyond the aims of this study to analyse the SI responses in such linguistic depth, this outcome opens doors to further research regarding the effect of language composition on the SI responses in Maltese-English bilingual children.

Both groups in this study demonstrated few difficulties in the first four sentences, which were constructed to be the shortest and least complex ones. However, once the length and complexity of the sentences increased, more errors emerged. While this pattern was evident in both groups, the percentage error was much higher for the clinical group. This discrepancy in SI performance between groups is consistent with previous studies, reporting weaker SI in children with LI across a variety of languages (e.g. Caselli, Monaco, Trasciani & Vicari, 2008; Eadie, Fey, Douglas, & Parsons, 2002; Smolík & Vávrů, 2014; Stokes et al., 2006), severe speech difficulties (Seeff-Gabriel et al., 2010), autism spectrum disorders (Riches et al., 2010) and intellectual impairments (Caselli et al., 2008; Eadie et al., 2002).

The insertion of a modifier (the adjective ‘red’) in sentence number 5 might possibly be the first cause of a significant increase in errors: 50% of the TD group and 96% of the clinical group. The most common error that emerged was the omission of content words⁶⁹. Within this sentence, two specific words were commonly omitted: the adjective ‘red’, irrespective of which language the test was administered in was commonly omitted in both TD and clinical groups. However, the clinical group also tended to omit another content word (plus its preceding article), ‘the children’. Omission errors of content words also emerged across the rest of the sentences (see table 6.10), examples of which are the omission of ‘running’ (sentence 6), ‘swim’ (sentence 9). These errors were common to both TD and clinical groups, with the percentage error being greater in the latter. Omission errors have already been reported in the literature as being a frequent occurrence (Chiat & Roy, 2008; Seeff-Gabriel et al., 2010). However, this finding which emerged from monolingual children with DLD, reported more omissions of function words and inflections rather than content words. The outcome of this study also seems to contrast with the findings from a study on

⁶⁹ The term ‘content words’ is used to refer to objects of reality and their qualities. They are mostly made up of nouns, lexical verbs, adjectives, and certain adverbs. They contrast with function words, which are words of less substantive meaning and mainly demonstrate grammatical relationships between content words. They include prepositions, pronouns, conjunctions, etc. (Ginzburg, Khidekel, Knyazeva & Sankin, 1979).

bilingual Farsi-English children (Komeili & Marshall, 2012), whose omission errors were similar for content and function words.

Other common errors that emerged in this SIT seemed to occur mainly within the verbs or verb phrases. This was found in both groups, again with a higher percentage error emerging in the clinical group. The errors consisted mainly of substitutions, additions and simplifications of *verb phrases*⁷⁰. Examples of this are: the substitution of ‘as soon as’ with ‘when’ (clinical group; sentence number 6), substitution of ‘had forgotten’ with ‘forgot’ (both groups; sentence number 8); substitution of ‘*bdew iċapċpu*’ / ‘started clapping’ with ‘*ċapċpu*’ / ‘clapped’ (clinical group; sentence number 10); the addition of ‘*qagħad*’ (‘stayed’) (TD group; sentence number 7) (these substitutions are acceptable for Maltese speakers in some contexts). This outcome contrasts with Komeili and Marshall’s (2013) findings on 8-year-old English monolingual and Farsi-English bilingual children, where they report more substitution and addition errors on *function words*. One addition of a function word ‘the’ was commonly observed in the TD group in sentence number 5, to produce ‘the mum’ instead of ‘mum’ (in English). However, keeping in mind that these children were all Maltese-English bilinguals, this addition could possibly be due to the influence of the Maltese grammar, despite their PL being English, where in Maltese, the article ‘*il-*’ (‘the’) commonly precedes the noun ‘*mama*’ (‘mum’). The variation in findings between this study on the performance of Maltese children in the SIT compared with reports from other languages (both monolingual and bilingual) highlights the difference in the way individuals of varied language backgrounds process linguistic information, and hence the importance of analysing and interpreting these linguistic data specific to each population.

⁷⁰ Maltese verbs inflect for tense (‘*niekol*’ (‘I eat’) → ‘*kilt*’ (‘I ate’)) and person (‘*niekol*’ → ‘*jiekol*’ (he ate) / ‘*tiekol*’ (she ate’)) through bound morphemes (Borg & Azzopardi Alexander, 1997).

The following chapter concludes this research. The limitations are discussed and recommendations for future research as well as clinical implications are presented.

Chapter 7. Summary and Conclusion

7.0 Chapter overview

The main aim of this research was to develop and construct an assessment battery of auditory processing and obtain data on typically developing children. An additional focus to this was to collect data from a clinical population and compare their performance with that of the typically developing group. This chapter presents the conclusions drawn from the research findings. It also puts forward the limitations of the study, provides recommendations for further research, and clinical implications for assessment of children suspected of auditory processing difficulties in Malta.

7.1 Conclusions

The following conclusions can be drawn from this thesis:

1. The developed and modified subtests were found to be reliable tools to include in the assessment battery.
2. A factor analysis of the tool divided the subtests into two factors: subtests incorporating linguistic stimuli and subtests not incorporating linguistic stimuli. The DPT was the only subtest that tapped into both factors.
3. In general, when the typically developing children were divided according to demographic factors, they performed similarly in the auditory and language processing subtests of the battery, with a few exceptions (as described in section 5.4).
4. The AP subtests using non-linguistic content were less likely to have an influence on the performance of the children forming the clinical group (with the exception of the DPT). The performance outcomes of children with neurodevelopmental disorders on tasks of temporal processing has been varied across research studies, with some reporting weaker performance in this group and others finding no significant difference. This might suggest that not all children with a neurodevelopmental disorder exhibit difficulties with temporal processing.
5. There was a difference in performance between the typically developing group and the clinical group on all AP subtests using linguistic stimuli, where the clinical group performed significantly worse.
6. The clinical group also performed significantly worse on all subtests of language processing. In the nonword repetition tests, while the group produced significantly more errors than the typically developing group, the error patterns were similar between the two groups. In the sentence imitation task the clinical group were found to exhibit more omissions and inaccurate imitations in the longer and more complex sentences.

7.2 Limitations

The limitations of the study are presented below. Some of which serve as recommendations for future research.

1. Selection of participants: Despite the large number of information letters and consent forms sent out over the course of two years as the data was being collected, the vast majority chose not to participate, resulting in a very low response of 6.4%. As a result of this, the target number of children to be assessed was not reached. In addition, a rather high percentage of the 6.4% who took part were diagnosed with another difficulty – further reducing the data obtained of typically developing

children. The data from children with other difficulties was still obtained but taken note of. These children were later grouped and analysed separately.

2. The data collection: The greatest obstacle encountered at this stage was the time factor. It took the researcher two hours per participant to complete all the subtests. In addition, due to the poor response rate, the researcher collected data from 130 children over the time course of the study. Furthermore, six of the children only attended the first session. In this case some tests were not carried out on these children. While it was an initial aim to collect enough data to bring out z scores and standardised scores across the independent variables for this assessment battery, the low response rate did not allow for this. Further data needs to be collected to fulfil this aim.
3. Pre-assessment screen: Although it has been recommended that both ipsi- and contralateral acoustic reflexes are included as part of the screening pre APD assessment, this study only administered ipsilateral acoustic reflexes. With a reported reduced contralateral acoustic reflexes in children with normal hearing thresholds but a suspicion of having APD (Saxena, Allen & Allen, 2005), this may deny the study some useful subject information. There seems to however be substantial diversity across populations in terms of whether individuals diagnosed with APD present with abnormal contralateral reflexes but normal ipsilateral reflexes (Ferre, 2012).
4. Exclusion of auditory neuropathy spectrum disorder (ANSI): Due to limited equipment and time availability it was not possible to fully exclude ANSD. A typical profile of ANSD includes:
 - a. present otoacoustic emissions,
 - b. absent acoustic reflex thresholds (ART),
 - c. varying pure tone thresholds,
 - d. varying word recognition scores,
 - e. poor performance on speech in noise tests.

When the behavioral test results indicate ANSD, an auditory brainstem response test (usually modified to include a comparison of compression 10 and rarefaction stimuli) is performed to confirm the diagnosis (Norrix & Velenovsky, 2014). In this study, all children underwent an audiometric assessment including pure tone audiometry, tympanometry and ART. Only children who passed this assessment were included. Absent ARTs were excluded in an attempt to eliminate subjects with potential ANSD. Exclusion of ANSD is of importance due to the overlapping clinical characteristics

with APD, such as the possibility of normal pure tone levels combined with poor speech recognition abilities, difficulty hearing in noise and poor temporal processing skills (Starr & Rance, 2015).

5. Cognitive screen: Although only children with no diagnosed developmental disorder, no history of speech and language delay and no reports from psychological or health care professional were included in the TD group for the study, a screen for cognition and learning disability was not included as part of the pre-assessment screen. Significant correlations have been found between AP and cognition (Tomlin, Dillon, Sharma & Rance, 2015). A cognitive screen would have thus fully ensured that children with a possible (unidentified) cognitive impairment or learning disability would not be included as part of the TD sample.
6. Questionnaire of (Central) Auditory Processing: Although the content was professionally translated, back-translated, and proof read, it was not assessed for readability. Readability of questionnaires has been found as a key component to its validity and reliability, where the importance of the questionnaires to be written at a reading level that an adult can comprehend is highlighted (Scientific Advisory Committee of the Medical Outcomes Trust, 2002).
7. Gaps-in-noise test: When a subject missed a gap, the researcher automatically assumed that it was the smallest gap being missed. This assumption could have been avoided if the subjects were asked to visually show what was being heard (for example by pressing a button when a gap is perceived or counting the noise segments using their fingers).
8. Results: The box plots illustrated throughout chapter 5 and appendix C depict outliers for every subtest in terms of each independent variable. Within this study it was chosen to retain the outliers. There are arguments that this might pose a limitation on the study, where the statistical analysis might not focus on modelling the majority of the sample population. But eliminating data points for the purpose of statistical analysis when there is no assignable cause should not be justified (Yang & Berdine, 2016). Hence, for the sake of avoiding possible data manipulation, outliers were retained.
9. Socioeconomic status: The investigation of SES in relation to the participants' AP skills could not delve as deep as the rest of the independent variables. SES effects

were added at a much later stage in the study (4 years post initial data collection), following recommendations that emerged from the MPhil to PhD transfer examination. All subjects were contacted to participate in this additional study but less than 50% showed interest. Thus, the analysis was carried out separately and SES could not be included in the regression analyses.

7.3 Further research

This study was the first in Malta to explore in depth the AP skills in the typically developing Maltese paediatric population. Some of the results emerging from this study have already been further built upon, to investigate the AP skills in varied clinical groups (Tabone et al., 2016) and the effects of SES on AP skills in Malta (Tabone et al., 2017).

The work carried out in this study has highlighted potential areas for further research:

1. The effect of handedness on processing skills has been previously explored in studies for some time (e.g. Briggs & Nebes, 1976; McKeever & VanDeventer, 1977; Vernooij et al. 2007). It would be interesting to examine the effects of handedness on the varied behavioural subtests of AP by collecting more detail on the handedness of the participants (through the Edinburgh Handedness Inventory (Oldfield, 1971)) and correlating these with the AP results.
2. Linked with handedness is laterality. Throughout the Dichotic digits (free recall) scoring, the sequence with which the participants recalled and repeated all four numbers correctly was also recorded (e.g. right ear, left ear, left ear, right ear). This opened an opportunity for further research in investigating the most commonly used patterns of recalling the digits. This analysis has already been carried out in previous studies. Abel and van der Werf (2009) examined the pattern with which adult subjects repeated double dichotic digits during free recall. They reported the response of digits presented to the left before the right (LLRR) and digits presented first in the sequence before the second ones (1122). Their findings were consistent with previous studies (Brainerd, Reyna, Harnishfeger, & Howe, 1993; Brainerd, 1995). Brainerd (1995) found that the weaker items are reported first – an effect which is referred to as *cognitive triage*.
3. It has been found that children suspected of having APD perform poorly when assessed through spatialised noise (Cameron, Dillon & Newall, 2006). ‘Spatial processing disorder’ has been acknowledged in the latest BSA position statement (2018) as a reduction in the ability to utilise spatial cues in order to hear in the presence of

background noise. While this study did not investigate this aspect of AP it offers opportunity to expand on the data already collected for this population.

4. In this study, the nonword repetition tests were analysed in terms of their percentage error across syllable length and structure complexity. Further analysis of the NWRT could investigate and compare the percentage amount of errors in high and low word-like nonwords across age groups. Studies show that phonotactic probability and word-likeness could also have an effect on the production accuracy of the nonword. Typically, the more word-like nonwords are repeated with greater accuracy than less word-like (Dollaghan, Biber, & Campbell, 1995; Gathercole, 1995). Individuals recognise nonwords whose sub-parts are made up of real words as more word like than those whose subparts are not supported in the lexicon (Munson et al., 2005). Bailey and Hahn (2001) have additionally analyzed the relation between word-likeness with the mental lexicon and found that the lexicon also influences a person's perception of word-likeness. Children have been reported to have more difficulty than adults in repeating nonwords of low phonotactic probability. However, this difficulty decreases with increasing age (Edwards, Beckman & Munson, 2004; Munson, 2001).
5. The nonword repetition-in-noise tests were presented using multispeaker speech babble at a SNR of between +5 and +8 and the performance of the TD and clinical groups recorded. It is interesting to further examine this performance using different noise types (such as steady-state speech-shaped noise and single speaker speech of the opposite and same gender) and variations in the SNR.
6. The temporal processing subtests all incorporated simple non-linguistic stimuli. Further investigations using acoustically complex non-linguistic stimuli (such as those reported in Scott, Blank, Rosen & Wise, 2000) could investigate and compare the performance of Maltese TD and clinical groups.

7.4 Clinical implications

The outcomes of this research may be useful to clinical professionals involved in the assessment of Maltese children suspected to have APD:

1. The QCAP, as was developed in this research and published in Tabone et al. (2016), could guide clinicians to gain initial understanding of auditory and listening difficulties that might warrant further assessment of AP skills.
2. With the linguistic component incorporated in some of the AP subtests, it was important to obtain population-specific results. Maltese children perform differently

to other populations on the same tests (such as the Dichotic digits test). Variability between populations is also evident in subtests not using linguistic content, further warranting the necessity of obtaining population-specific trends. These results are provided in this thesis.

3. Clinical professionals are provided with a clearer picture of what to expect from children aged 7;00 to 9;11 years, helping them to decide whether the children's performance is typical.
4. Knowing the child's specific difficulties can help clinical professionals to devise individualised intervention strategies.

The trends derived from this study have created a starting point to further research and clinical management for Maltese children suspected of auditory processing difficulties.

With the varying tentative conclusions across studies as to what *is* APD, it is hoped that this research will open doors to further local research that will contribute to the global APD debate.

Glossary

Attention deficit hyperactivity disorder	A disorder which is characterised by symptoms of inattention and/or hyperactivity-impulsivity which must be chronic or long-lasting, impair the person's functioning, and cause the person to fall behind normal development for his or her age.
Auditory neuropathy spectrum disorder	Normal cochlear function accompanied with abnormal brainstem responses, representing a dyssynchronous auditory nerve.
Auditory processing	The ability of the central nervous system to perceptually process auditory information coming from the auditory channels
Bartlett's test of sphericity	Tests the hypothesis that a correlation matrix is an identity matrix. It indicates whether the variables are unrelated and thus unsuitable for structure detection, or otherwise.
Bilingual	Defined in the broadest sense, bilingualism includes people who use two (or more) languages (Gertken, Amengual & Birdsong, 2014).
Categorical variable	A variable with two or more categories
Cronbach's Alpha	A statistic generally used as a measure of internal consistency. It shows how closely related a set of items are as a group.
Cognitive control	The formation, maintenance, and realisation of internal goals.
Consonant cluster	Two adjoining consonants in the same syllable.

Consonant sequence	Two adjoining consonants spread over two syllables.
Correlation	A statistical relationship between two or more variables. Variables are correlated when movement in one variable is complemented by the movement in another variable.
Dependent variable	The measured variable which is affected by other variables
Developmental language disorder	A condition where children have difficulties understanding and/or using spoken language.
Dichotic listening	A skill in which individuals direct their attention to one conversation and disregard any other voices heard simultaneously.
Eigenvalue	A scalar associated with a given linear transformation of a vector space.
Error analysis	A study of the types and causes of language errors.
Error pattern	Speech errors that typically developing children use to simplify speech.
Event-related potentials	The EEG changes that are time locked to sensory, motor or cognitive events.
Factor analysis	Investigation of the underlying variance structure for a set of correlation coefficients
Formant	A representation of the vocal tract resonance in terms of its harmonics and is characterized by a dark horizontal band across time.
Independent variable	Variable that is not influenced by other variables
International Classification of Diseases (ICD)	The international standard diagnostic tool for epidemiology, health management and clinical uses. It classifies diseases and other health issues on various kinds of health records and death certificates.
Inter-stimulus intervals	The temporal interval between the offset of one stimulus to the onset of another.
Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO)	A statistic indicating the proportion of variance in variables that may be caused by underlying factors.
Literacy difficulties	Defined under the DSM-5 as Specific Learning Disabilities (SLD). This impedes the ability to learn or use specific academic skills of reading, writing, or arithmetic.
Neurodevelopmental disorders	A communication disorder that includes various currently separate markers, such as impairments in language, literacy, attention and behavior difficulties.
Non-parametric test	A statistical test that does not make any assumptions about the underlying distribution.
Parametric test	A statistical test that makes assumptions about the parameters of a population distribution from which data are extracted.
Phoneme	The smallest contrastive unit in the sound system of a language
Phonology	The study of how sound organisation in natural languages.
Phonotactic probability	The frequency with which a phonological segment,

	and a sequence of phonological segments occur in a given position in a word.
Prevalence	A statistical model referring to the number of cases in a disease or deficit which are present in a specific population at a given point in time.
Regression analysis	A set of statistical processes used for estimating the relationships among variables and exploring the forms of relationships.
Reliability	The stability or consistency of results when taken over time or across raters.
Scree plot	A decreasing function demonstrating the variance explained by every factor in the factor analysis.
Spectrogram	A visual way of representing the signal strength, or “loudness”, of a signal over time at various frequencies present in a particular waveform.
Spondaic words	Two-syllable words that have equal stress on each syllable
Stratum	A language that influences, or is influenced by another.
Structural processes	Phonological simplifications that involve some alteration to the structure of a word.
Systemic processes	Phonological simplifications that do not alter the syllable structure of a word.
Temporal processing	The ability of the auditory system to decipher the dynamic durational features of a sound signal within a time interval
Validity	The degree with which a tool accurately assesses what it is meant to assess, so that the outcome of the measurement parallels the real situation in the world.

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