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*Research paper*

# AUDITORY AND LANGUAGE PROCESSING SKILLS IN MALTESE CHILDREN: A COMPARATIVE STUDY

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**Abstract.** Auditory processing disorder is described as a mixture of unrefined listening skills which, despite normal hearing, causes poor speech perception. These difficulties have also been reported in children with a diagnosis of language impairment (LI), literacy difficulties (LD)[1], and attention-deficit/hyperactivity disorder (ADHD). The purpose of this study is to describe and compare the listening performance of typically developing (TD) children with those diagnosed with LI, LD, and ADHD on an assessment battery of auditory processing (AP) and language processing (LP). One hundred and one TD children and 53 children with a clinical diagnosis were assessed using four subtests of AP presenting linguistic stimuli, three AP subtests with non-linguistic stimuli and an assessment of LP. Parents of all children were required to fill in a questionnaire related to their listening difficulties. Parental report for the TD group on average yielded the lowest score, indicating fewer difficulties with listening skills in the TD group. The listening difficulties exhibited in the Maltese participants diagnosed with LI, LD and ADHD were mainly specific to the AP subtests using linguistic stimuli. The LI and LD groups generally performed significantly worse than the TD group on all AP subtests using linguistic stimuli, while the ADHD group performed significantly worse than the TD group on some of these tests. The same pattern did not emerge for the subtests using non-linguistic stimuli. Few significant effects between groups were evident. The LI groups were found to perform the weakest in all tests of language processing.

**Keywords:** auditory processing, language processing, children, language impairment, literacy difficulties, attention-deficit/hyperactivity disorder

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1 Throughout this text, the term 'literacy difficulties' will be used to refer to any impairment or difficulty with reading and spelling.

## *1* Introduction

Auditory processing (AP) is the ability to listen, understand and respond to information heard through the auditory channels. It involves both the detection of sound and its transmission through the auditory pathways to the brain (Yalcinkaya, Muluk & Sahin, 2009). The information processing theory states that both bottom-up (sensory encoding) and top-down factors (cognition, language, and higher-order functions) work together and exert a strong influence on information processing (Mülder, Rogiers & Hoen, 2007). Auditory processing disorder (APD) is complex and heterogeneous in nature, resulting in a lack of consensus in terms of definition, assessment and diagnostic criteria (Kamhi, 2011; Wilson & Arnott, 2013). It 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).

Although there is agreement regarding the manifested symptoms, there are conflicting reports concerning the cause of APD. Children presenting with this condition are reported to find difficulty understanding verbal instructions and tend to exhibit poor attention (British Society of Audiology, 2011; Moore, 2011). Listening skills are key to the enhancement of language and learning skills (Jourkouye & Vahdani, 2013). Moore et al. (2010) investigated the correlation between tests of AP and attention and cognition. Their results indicated that attention and cognitive scores are valid predictors of communication, suggesting that the primary cause of APD is a difficulty in attention skills. In fact, children with attention-deficit/hyperactivity disorder (ADHD) have been documented to demonstrate listening difficulties (e.g. Lucker, Geffner & Koch, 1996; Keith & Engineer, 1991; Ludlow et al., 1983, Sutcliff et al., 2006; Huang et al., 2012). A high comorbidity between APD, language impairment (LI) and reading disorder has emerged in studies (e.g. Sharma, Purdy & Kelly, 2009). Similarly, parental report of communication, listening skills and general behaviour in children who had previously been diagnosed with either specific language impairment (SLI)[2] or APD have resulted in a very similar performance (Ferguson et al., 2011).

Some studies have investigated the link between bilingualism and auditory processing (e.g. Krizman et al., 2014; Golestani et al., 2007; Wong et al., 2008). Of interest, Krizman et al. (2014) collected data from auditory evoked responses together with data from attentional control and language skills in monolingual and bilingual speakers. The bilingual speakers revealed better attentional control and increased consistency in brainstem and cortical responses to speech sounds. Many Maltese individuals are considered to be early sequential bilingual speakers to whom the second language is introduced soon after the acquisition of the first language (Grech & McLeod, 2011). To date, there has been no published data on auditory processing in the Maltese paediatric population. In light of this, and considering the local bilingual situation, it is relevant to examine the auditory processing skills in this population, and compare the performance of typically developing (TD) children with that of children diagnosed with LI, literacy difficulties (LD) and ADHD. This study investigated the following issues:

(1) How do the perceived listening difficulties of children diagnosed with LI, LD, and ADHD compare with TD children?
(2) Is there a significant difference between the performance of TD children and those with a diagnosed LI, LD, and ADHD on an assessment battery of auditory and language processing?
(3) Is there a significant difference in the performance of each clinical group on the assessment battery?

## 2 Method

### 2.1 Participants

The total sample consisted of 154 children, aged between 7;00 and 9;11 years. The children were allocated to four different groups: TD, LI, LD and ADHD. The TD group ($N$ = 101) was recruited by means of random sampling via the National Statistics Office of Malta, which supplied a random list of addresses of families with children in the age range needed. The selection criteria are shown in Table 1. The children forming the LI group ($N$ = 11) were identified and recruited through the Speech Language Department within the Ministry of Health, Malta. A set of criteria (Table 1) was devised to recruit children based on specific characteristics rather than on the diagnosis of SLI or LI given by the respective speech-language pathologist (SLP). This approach to recruitment was motivated by the fact that locally, SLPs tend to differ in the test batteries and diagnostic criteria used to identify SLI. Recruiting children on the basis of these criteria allowed for more uniformity in the LI participant group. The selection criteria were based on Leonard (2014), with additional consideration of the bilingual context specific to the bilingual situation in Malta.

**Table 1.** Selection criteria for the TD participants and those with LI

| TD | LI |
|---|---|
| Maltese citizen | Maltese citizen |
| Aged between 7;0 and 9;11 years | Aged between 7;0 to 9;11 years |
| Bilingual: Maltese/ English | Bilingual: Maltese/English |
| No history of hearing impairment/ chronic ear infections | No history of hearing difficulties/chronic ear infections |
| No speech and language impairment | Currently receiving speech-language therapy services due to presenting language difficulties |
| No cognitive impairment | Non-verbal IQ of 85 or better if provided with a report |
| No attention difficulties | No attention difficulties |
| No neurological pathology | No evidence of seizure disorder, cerebral palsy and/or brain lesions |
| No behaviour problems | No symptoms of impaired interactions as in autism spectrum disorder |
| No long-term medication | Normal oral structure and oral motor function but might or might not have co-morbid persisting articulatory/phonological difficulties |

The children included in the LD group ($N$ = 12) were recruited following interest from the parents on receiving the participation letter targeting the TD sample. These children had all been diagnosed with literacy difficulties by an educational psychologist. The criteria used for including these children were similar to the LI group, with the difference that they did not exhibit any oral language impairment.

The final group recruited for this study comprised the children diagnosed with ADHD ($N$ = 30). They were recruited through the national Child Guidance Clinic. All participating children were diagnosed with ADHD by a psychologist. They were to have no current intake of medication, not be attending any speech-language therapy services and present with no additional cognitive and language disorders.

The research study obtained approval from the University Research Ethics Committee (UREC) at the University of Malta. Permission to access to potential participants was obtained from the National Statistics Office, the Speech-Language Department and the Child Guidance Clinic. Signed parental consent and verbal child assent were acquired from all participants.

2 Traditionally described as a deficit in language structure (Davies, Andrés-Roqueta & Norbory, 2016).

## 2.2 Test procedures

### 2.2.1 Peripheral hearing

Each child underwent an initial hearing screening, including an otoscopic examination, immittance audiometry and pure-tone audiometry. All participants exhibited no abnormalities on otoscopic examination and also showed normal hearing levels and immittance measures.

### 2.2.2 Questionnaire

Participants' parents completed a questionnaire available in both English and Maltese (Questionnaire of (Central) Auditory Processing; QCAP) (Appendix 1: English version), developed and validated as part of another study (Tabone, in progress), and requesting information about listening difficulties commonly found in children suspected of presenting with APD. This questionnaire consists of five questions requesting background information related to a history of otological problems and other developmental disorders. This is followed by 20 items relating to listening behaviour in different listening environments. The children are rated on a 5-point Likert scale, where a score of 5 indicates substantial difficulty, while a score of 1 indicates no difficulty.

### 2.2.3 Assessment battery of auditory processing

Auditory processing skills were assessed using five behavioural tests. All tests were presented through TDH-39 earphones connected to a clinical audiometer at 50 dB HL. Binaural integration and separation were examined through two subtests of the Dichotic Digit Test (DDT) (Musiek, 1983), specifically during the 'free recall' (FR) and 'simple focused attention' (SFA) tasks. The participants were presented with four numbers, two presented to each ear simultaneously. In the FR task they were requested to repeat all four numbers, while the SFA task required them to focus on one ear and repeat only what was heard in that ear, ignoring the other ear. Throughout these tests, both ears were tested simultaneously. Temporal processing was assessed through the Duration Patterns Test (DPT) (Musiek, Baran, & Pinheiro, 1990), Frequency Patterns Test (FPT) (Musiek, 1994) and the Gaps-in-Noise Test (GIN) (Musiek, 2003). The Patterns Tests included sequences of three consecutive tones, differing in either duration or frequency. A total of 30 items were administered (15 in each ear) and the participants were to identify the patterns (long versus short or high versus low). The GIN test required the children to identify gaps ranging between 2 and 20 ms embedded in bouts of white noise. Auditory closure was assessed through two subsets of language specific (Maltese- and English-based) non-word repetition tests (NWRT) in the presence of background speech babble (NWRT(n)) at approximately a +5 signal-to-noise ratio (SNR) (Calleja, Grech, & Bamiou, 2012). Each subtest consisted of a total of 24 non-words of varied syllable length and complexity, which the participants were to repeat. The non-words were spoken by a female native Maltese speaker. These tests presented stimuli to the right and left ears separately, randomising the ear with which the test first starts. The DDT, DPT, FTP and GIN were scored in terms of percentage correct responses. The responses from the two NWRT(n) were phonetically transcribed and scored for the total percentage words with errors.

### 2.2.4 Tests of language processing

A language specific NWR task, similar to the NWRT(n) but with no background noise (NWRT(qu)), was used to assess phonological working memory. The participants were to repeat the non-words presented. As in the NWRT(n), each list (Maltese- and English-based) included 24 items. The performance was scored in the same way as the NWRT(n). The Sentence Imitation Task (SIT), part of the Language Assessment for Maltese Children (LAMC) (Grech, Franklin & Dodd, 2011), was included to assess the children's working memory and language processing skills through comprehension followed by the reconstruction of sentences. They were required to repeat 10 sentences (presented in their primary language) of increasing length. A score of 2 was given if the complete sentence was repeated clearly and correctly, a score of 1 was given when 50% or more of the sentence was repeated and a score of 0 was given if less than 50% of the sentence was repeated.

## 2.3 Procedure

The TD participants completed the entire test battery in two sessions lasting approximately one hour each. The children forming the clinical groups required a third session due to the inability to complete all subtests within the two sessions. This was expected given their diagnoses. These children required more breaks and repeated explanation of the tasks. During each session, frequent short breaks were provided. All testing was carried out in a sound treated room. The administration sequence of the auditory and language processing tests was varied within the sessions.

## 2.4 Statistical analysis

All measures were tested for normality using the Shapiro-Wilk test due to the relatively small sample sizes. The results indicated that the data for the TD group were not normally distributed. The distribution of data for the clinical groups varied. The data obtained from the ADHD group were not normally distributed, with the exclusion of the four NWRT subtests. The other two clinical groups brought out data of generally normal distribution. In light of the variation in distribution, the data were analysed using non-parametric means. Significance was established to be $\leq 0.05$.

## 3 Results

### 3.1 Questionnaire

The QCAP correlated moderately with the Children's Auditory Processing Performance Scale (CHAPPS) (Smoski, Brunt, & Tannahill, 1998) ($p = 0.05$) and demonstrated strong internal and test-retest reliability (>0.90; $p = 0.01$). Parental report on various aspects of listening skills was obtained through the QCAP, the means of which are plotted in Figure 1. Responses to the questions were analysed to provide a total score of the perceived (subjective) difficulty and also in terms of specific skills emerging in an exploratory factor analysis (Tabone, Grech & Bamiou, 2016a), namely auditory attention and memory, conversation skills, sensory stimulation, listening in noise, and social situations. Figure 1 demonstrates that the parental report scores for the TD group were on average lower than those for all the clinical groups, indicating fewer difficulties in the former with listening skills.

The Kruskal-Wallis test demonstrated statistically significant differences ($p < 0.01$) between groups in both the total questionnaire score and each of the subscale scores (Table 2). Through the Mann-Whitney test, significant differences were evident between the TD group and each of the clinical groups, with the latter obtaining poorer scores. No significant differences between clinical groups emerged, suggesting that similar listening difficulties were reported by parents of children in the clinical groups.

The total QCAP score was correlated with each of the AP subtests in the assessment battery. Significant correlations were found between the QCAP and all subtests using linguistic stimuli. The stronger correlations were with the DD tests: DD(FR) on the right ($r = -0.42$, $p < 0.001$) and left ($r = -0.45$, $p < 0.001$) and the DD(SFA) in both ears (right:

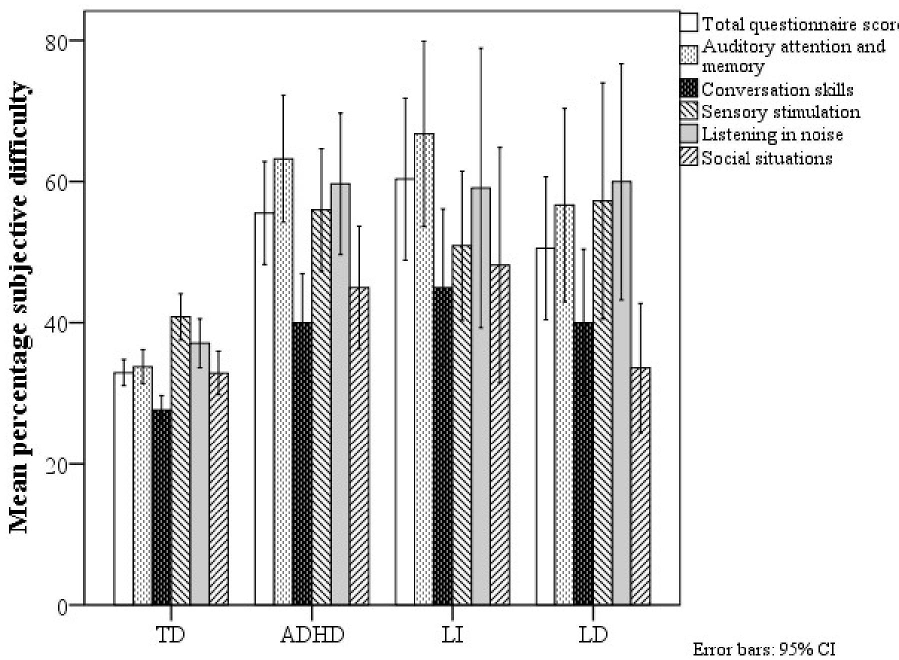



**Figure 1.** Mean scores of listening skills as reported by parents in the QCAP

**Table 2.** Comparison of means in the QCAP

| QCAP | Kruskal-Wallis | | | Mann-Whitney | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | χ2 | df | *p* | TD vs ADHD | TD vs LI | TD vs LD | ADHD vs LI | ADHD vs LD | LI vs LD |
| | | | | *p* | *p* | *p* | *p* | *p* | *p* |
| Total score | 53.6 | 3 | **<0.001** | **<0.001** | **<0.001** | **<0.001** | 0.669 | 0.233 | 0.138 |
| Auditory attention and memory | 53.3 | 3 | **<0.001** | **<0.001** | **<0.001** | **<0.001** | 0.757 | 0.239 | 0.122 |
| Conversation skills | 29.5 | 3 | **<0.001** | **<0.001** | **0.001** | **0.001** | 0.421 | 0.789 | 0.390 |
| Sensory stimulation | 17.8 | 3 | **<0.001** | **0.001** | **0.042** | **0.023** | 0.653 | 0.976 | 0.665 |
| Listening in noise | 30.1 | 3 | **<0.001** | **<0.001** | **0.004** | **0.003** | 0.917 | 0.929 | 0.868 |
| Social situations | 16.4 | 3 | **0.001** | **0.001** | **0.007** | 0.447 | 0.753 | 0.171 | 0.149 |

**Table 3.** Comparison of means in the auditory processing subtests using linguistic stimuli

| Subtests using linguistic stimuli | Kruskal-Wallis | | | Mann-Whitney | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\chi 2$ | df | *p* | TD vs ADHD | TD vs LI | TD vs LD | ADHD vs LI | ADHD vs LD | LI vs LD |
| | | | | *p* | *p* | *p* | *p* | *p* | *p* |
| DDT:FR (right) | 36.41 | 3 | **<0.001** | **<0.001** | **<0.001** | 0.334 | 0.828 | **0.005** | **0.008** |
| DDT:FR (left) | 36.01 | 3 | **<0.001** | **<0.001** | **<0.001** | **0.003** | **0.018** | 0.770 | **0.043** |
| DDT:SFA (right) | 19.65 | 3 | **<0.001** | **<0.001** | **0.007** | 0.247 | 0.532 | 0.147 | 0.300 |
| DDT:SFA (left) | 25.90 | 3 | **<0.001** | **<0.001** | **0.009** | **0.012** | 0.873 | 0.301 | 0.748 |
| mNWRT(n) | 22.20 | 3 | **<0.001** | 0.053 | **<0.001** | **0.009** | 0.147 | 0.441 | 0.300 |
| eNWRT(n) | 22.38 | 3 | **<0.001** | **<0.001** | **0.016** | 0.166 | **<0.001** | **0.002** | 0.412 |

(a)

(b)

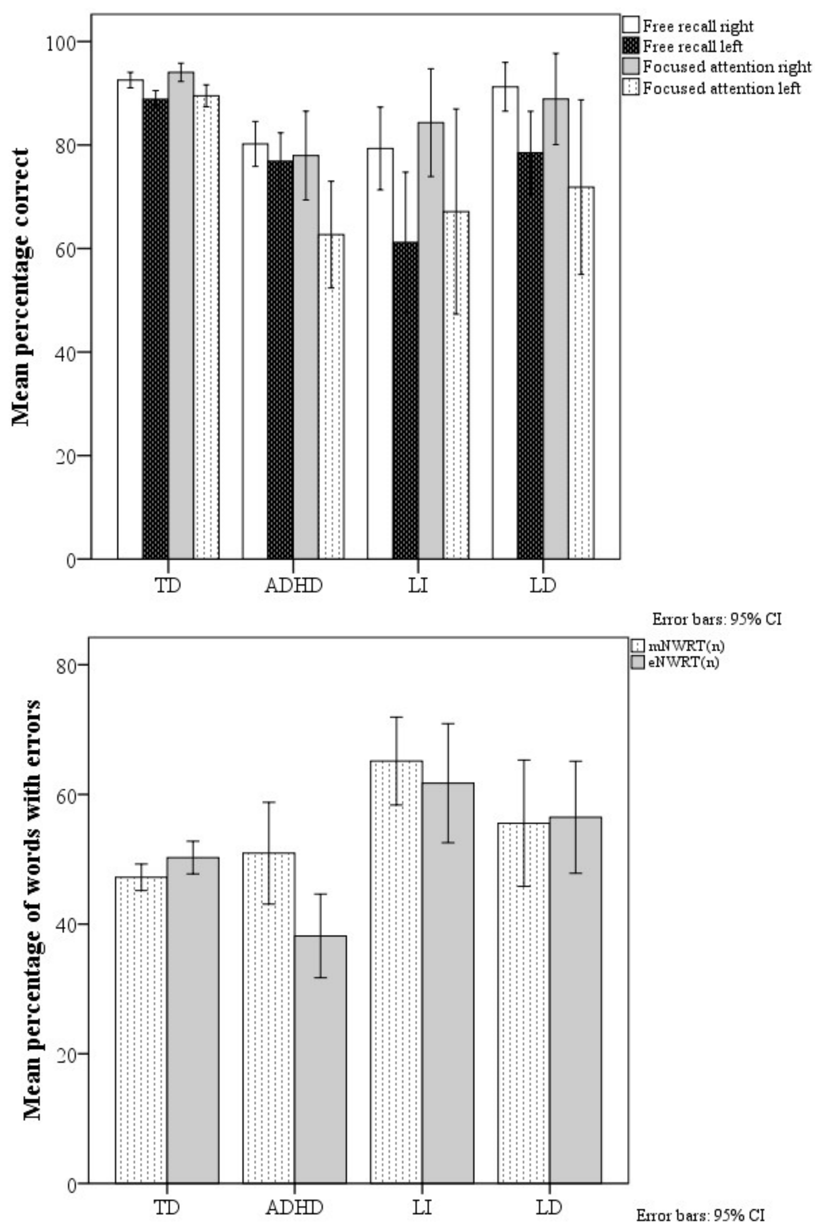



**Figure 2.** Mean scores obtained from auditory processing subtests using linguistic stimuli: (a) mean percentage correct scores from the DDT subtests (b) mean percentage of words with errors in the Maltese and English NWRTs in noise.

**Table 4.** Comparison of means in the auditory processing subtests using non-linguistic stimuli

| Subtests using non-linguistic stimuli | Kruskal-Wallis | | | Mann-Whitney | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\chi 2$ | df | *p* | TD vs ADHD | TD vs LI | TD vs LD | ADHD vs LI | ADHD vs LD | LI vs LD |
| | | | | *p* | *p* | *p* | *p* | *p* | *p* |
| DPT (right) | 21.3 | 3 | **<0.001** | **<0.001** | 0.225 | 0.094 | **0.001** | **0.002** | 0.365 |
| DPT (left) | 7.05 | 3 | 0.070 | 0.437 | 0.142 | **0.040** | 0.103 | **0.046** | 0.562 |
| FPT (right) | 3.49 | 3 | 0.332 | 0.120 | 0.762 | 0.602 | 0.612 | 0.140 | 0.331 |
| FPT (left) | 9.49 | 3 | **0.023** | **0.003** | 0.792 | 0.602 | 0.124 | 0.074 | 0.552 |
| GIN (right) | 0.53 | 3 | 0.912 | 0.671 | 0.537 | 0.537 | 0.674 | 0.724 | 0.557 |
| GIN (left) | 4.73 | 3 | 0.192 | **0.049** | 0.374 | 0.374 | 0.226 | 0.914 | 0.557 |

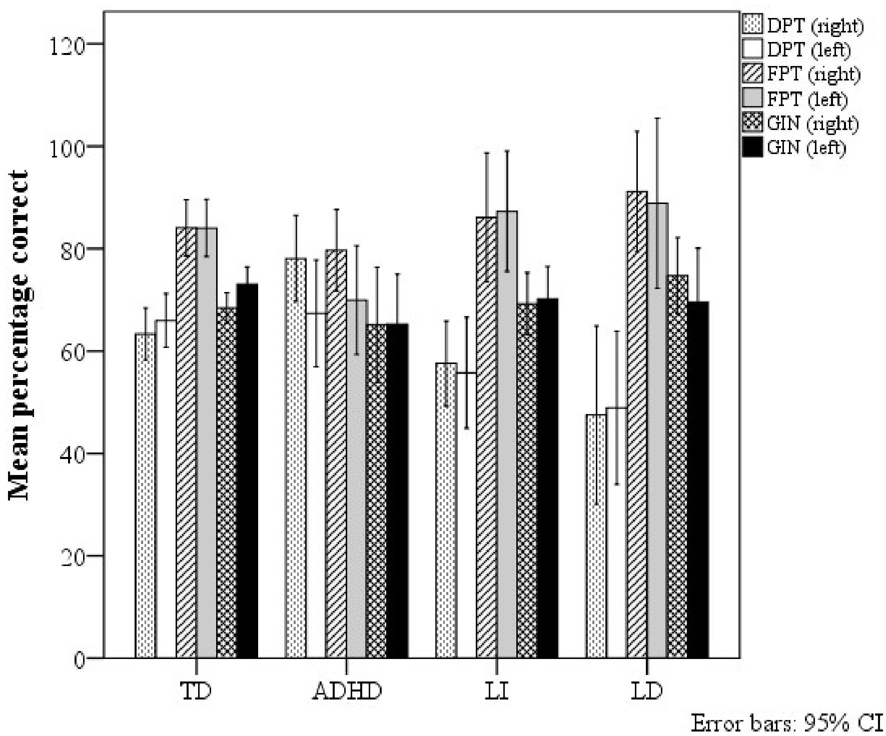
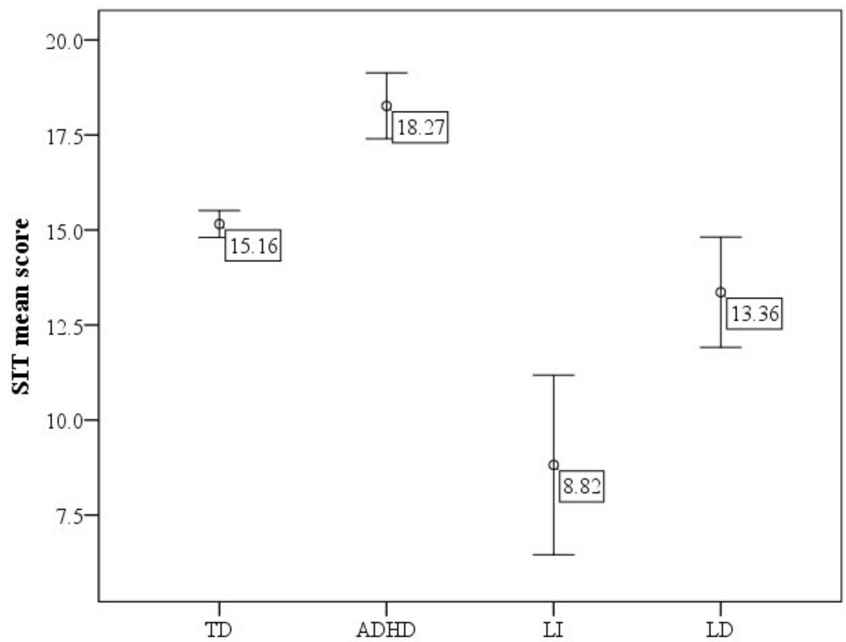



**Figure 3.** Mean scores obtained from auditory processing subtests using non-linguistic stimuli

**Table 5.** Comparison of means in the tests of language processing

| Subtests using linguistic stimuli | Kruskal-Wallis | | | Mann-Whitney | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\chi 2$ | df | *p* | TD vs ADHD | TD vs LI | TD vs LD | ADHD vs LI | ADHD vs LD | LI vs LD |
| | | | | *p* | *p* | *p* | *p* | *p* | *p* |
| SIT | 65.59 | 3 | **<0.001** | **<0.001** | **<0.001** | **0.008** | **<0.001** | **<0.001** | **0.003** |
| Maltese NWRT(qu) | 33.40 | 3 | **<0.001** | 0.758 | **<0.001** | **0.005** | **<0.001** | **0.010** | **0.006** |
| English NWRT(qu) | 25.88 | 3 | **<0.001** | 0.054 | **<0.001** | 0.164 | **<0.001** | **0.027** | **0.012** |

(a)




(b)

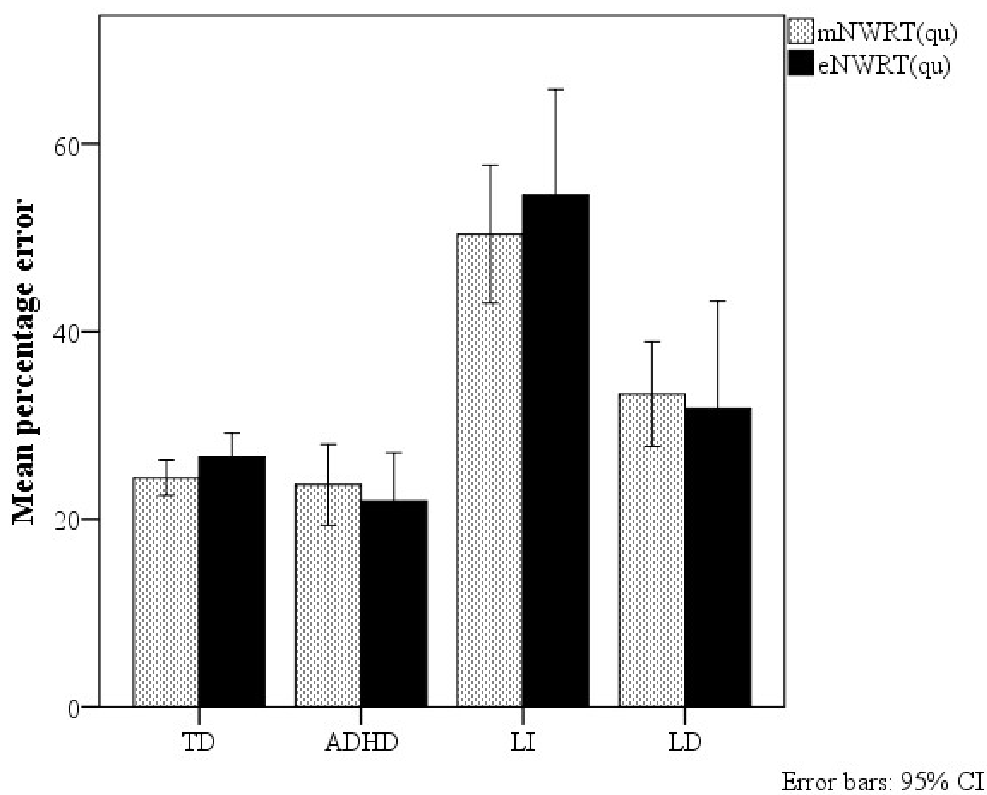



**Figure 4.** Mean scores obtained from the subtests of language processing: (a) mean scores from the SIT (b) mean percentage of words with errors in the Maltese and English NWRTs in quiet

$r = -0.40$, $p < 0.001$; left: $r = -0.41$, $p < 0.001$). Weaker but significant correlations were found with both Maltese-based ($r = 0.24$, $p = 0.003$) and English-based ($r = 0.18$, $p = 0.047$) NWRT(n) tests. With regards to the AP subtests with non-linguistic content, significant correlations only emerged in the left ear of two of the subtests: the FPT ($r = -0.21$, $p = 0.01$) and the GIN ($r = -0.25$, $p = 0 .002$).

### *3.2 Assessment battery of auditory processing*

The auditory processing tests were divided into two main sections following results of an exploratory factor analysis (Tabone, Grech & Bamiou, 2016b): subtests using linguistic stimuli and subtests using non-linguistic stimuli. The former included two DDT and two NWRT(n) subtests, while the latter consisted of the DPT, FPT and GIN tests. Group results were compared for each of the subtests. The Kruskal-Wallis test demonstrated a significant difference between groups in all subtests using linguistic stimuli (Table 3). 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 (Figure 2a). 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.

The Maltese and English NWRT(n) subtests (mNWRT (n) and eNWRT(n) respectively) revealed significant group differences. The ADHD group was found to perform significantly better than all other groups on the eNWRT(n) (Figure 2b) and scored similarly to the TD group on 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.

There were few significant differences between groups in the subtests using non-linguistic stimuli (Table 4). Generally, significant differences 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 (Figure 3).

### *3.3 Tests of language processing*

The LI group was found to perform the weakest in all tests of language processing (see Figures 4a and 4b). The difference in performance was significant when compared with all TD, ADHD and LD groups (Table 5). There was no significant difference between the TD and ADHD groups on the NWRT subtests. However, on average the ADHD group performed significantly better than the TD group on the SIT. These two groups were also found to obtain better scores than the LD group on the tests of language processing.

## *4* Discussion

This study set out to investigate the performance of Maltese children on an array of auditory and language processing tests and draw out comparisons between TD and clinical groups. Participant groups' performance on the specific components of the test battery is discussed next.

### *4.1 Questionnaire*

Parental report through the use of questionnaires is a relatively inexpensive and quick method to document the perceived listening difficulties of children and is commonly used as part of an APD assessment battery (Moore et al., 2012). All clinical groups performed significantly worse than their TD peers on the QCAP, suggesting that children diagnosed with LI, LD and ADHD also tend to exhibit listening difficulties. This result was consistent with studies investigating the listening difficulties of children suspected to present with APD by means of a questionnaire (e.g. Barry et al., 2015; Sharma et al., 2014). Results of this study further showed that the children diagnosed with LI and ADHD were reported as having difficulties in all subdomains of the QCAP. The children with LD did not present with a significant difference from the TD or other clinical groups in the 'social situations' subdomain. This might suggest that the difficulties in social situations exhibited by the children with LD might not be as pronounced as those of the other clinical groups. The results also demonstrated no significant difference between the scores obtained from the different clinical groups, suggesting that parents perceive their children as having similar listening difficulties despite the different diagnoses. This outcome is comparable with that reported by Ferguson et al. (2011), who obtained parental reports on auditory processing, communication skills and attention levels in mainstream school (MS) children and those diagnosed with SLI or APD. Some of the children in each group were also diagnosed with dyslexia, ADHD and autism spectrum disorder. The authors found that overall, the MS children performed better than the clinical groups across all domains. They also found no difference in performance between the clinical groups in communication, auditory attention and memory.

### *4.2 Assessment battery of auditory processing*

The participants in the clinical groups were formally diagnosed by a speech-language pathologist (for LI), and a psychologist (with LD or ADHD). None of them were assessed by an audiologist and were therefore not given a diagnosis of APD. However, all were reported to have listening difficulties despite exhibiting normal hearing – a typical characteristic of APD (de Wit et al., 2016). It is therefore suspected that these children might have also presented with APD.

Dichotic listening tasks are the most frequently used in APD assessment batteries (Cameron et al., 2016) and have been found to correlate substantially with everyday listening difficulties (Tomlin et al., 2015). Nevertheless, it is now known that dichotic listening relies heavily on cognitive abilities such as attention (DeBonis, 2015), short-term auditory memory, and language skills (Loo, Bamiou & Rosen, 2013). In light of this literature, the findings of this study are not surprising. The DDTs did in fact correlate best with the QCAP, which includes sections on '*auditory attention and memory*' and '*conversation skills'*, and resulted in all clinical groups performing significantly worse than the TD group on the DDTs, either in both or one ear. This result is consistent with previous studies (e.g. Barry et al., 2015; Rocha-Muniz et al., 2014) who found that all children in their clinical groups performed worse than their TD group. Contrasting results were however reported by Sharma et al. (2014), where the children with listening difficulties performed age appropriately on DDTs. It must be noted that the children in the latter study were older than the ones reported in the present study and those by Barry et al. (2015) and Rocha-Muniz et al. (2014), which might indicate that skills in dichotic listening are still developing in younger children as investigated in this study.

Speech-in-noise tests are frequently used as part of APD test batteries (e.g. Moore et al., 2010; Lagacé et al., 2011). These tasks require the listener to recognise the intended speech signal from background noise. It has been suggested that this skill entails both the encoding of frequency and temporal information in the brainstem, and the consequent auditory attention and working memory processes (Anderson et al., 2010), which are needed to excerpt the signal from the noise and facilitate speech understanding (DeBonis, 2015). While some authors claim that the factor underlying the ability of listening in noise is working memory (e.g. Rudner, Rönnberg & Lunner, 2011), others (e.g. Ferguson et al., 2011) propose that attention skills are crucial. The LI and LD children in this study performed significantly worse than the TD group in one or both of the NWRT(n) subtests. The linguistic element present in the stimuli could have been an underlying factor since these groups also performed worse in the NWRT(qu) subtests. NWRT and sentence imitation (SI) have been frequently documented as clinical markers of LI. NWR taps into linguistic processing at a phonotactic level, without any inclusion of meaning (Thordardottir & Brandeker, 2013), while SI displays grammatical abilities, short-term memory and working memory (Riches, 2012). Studies investigating speech in noise using non-word syllables (e.g. Moore et al., 2010; Ferguson et al., 2011), single words (e.g. Rocha-Muniz et al., 2014) and sentences (e.g. Ferguson et al., 2011) suggested that children with suspected APD and comorbid LI tend to perform poorly on non-word and word repetition, but not so much on SI in noise. The emergent findings of SI (in quiet) in this study already resulted in a significantly worse performance by the LI and LD groups in comparison with the TD participants. The ADHD group did not perform significantly worse than the TD group on both NWRT(qu) and SI tasks. This result seems to be in line with previous research (e.g. Redmond, Thompson & Goldstein, 2011), who investigated the performance of children diagnosed with SLI and ADHD on tests of SI and NWR and found no difference in performance between the TD and ADHD groups on both tasks, but a significant difference with their LI group. It would be interesting to investigate the performance on a SI task in noise in future research on this population. It would be of further interest to investigate the performance across varying levels of noise.

It has also been suggested that '*attention*' measures predict performance on speech-in-noise tests (Moore et al., 2010). This finding did not emerge in the current study, where the ADHD group performed well in the speech-in-noise task, despite the reported listening difficulties. A possible reason for this outcome could be the extra time (compared with the TD group) that these children were given to complete the tasks. Although the study could have opted to allocate the same time frame across groups to process all the tasks in the assessment battery, it was of greater interest to investigate the accuracy with which the tasks were completed rather than the speed.

Tallal's (2004) theory of temporal processing suggests that LI occurs due to difficulty in managing sound stimuli presented rapidly. In relation to this, Loo et al. (2013) found poorer gap detection thresholds in children with language difficulties. On the other hand, Sharma et al. (2009) reported that children with comorbid LI and reading disorder performed well on their temporal processing task using the FPT. Rosen, Adlard, and van der Lely (2009) explored claims that non-speech auditory deficits underlie LI but concluded that this is unlikely since a high percentage of their sample with a LI performed within normal limits on tasks of masked thresholds. The results that emerged from the group performances in this study resulted in no significant differences in both ears between the TD and clinical groups on tasks using non-linguistic stimuli. This is in contrast to the subtests using linguistic stimuli where the LI and LD groups performed significantly worse than the TD group. The significant correlations that emerged between QCAP and all the AP subtests with linguistic content suggest that there might be a stronger link between perceived listening difficulties and the performance on complex listening situations that involve language to some extent. A similar result has already been reported. Grube et al. (2014) analysed the relationship between auditory and language processing in children with LD in comparison to TD children. They found no significant differences between the two groups on auditory processing tasks of pitch, rhythm and timbre. The children with literacy difficulties did however perform poorer on phonological language and literacy tasks.

### *4.3 Limitations*

This study included relatively small samples. Considering that to date there are no data on the performance of TD children on auditory processing tests, a larger sample could bring out more robust norms. Larger samples of the clinical groups could allow for better generalisation to the population of children diagnosed with LI, ADHD, and LD. Although this research established criteria to recruit the clinical groups, their initial diagnoses were given by different professionals, resulting in possible variability depending on the diagnostic tools used. Moreover, the data were collected by different researchers, increasing the chance of variability, despite the stringent scoring rules. A final limitation could be that other newly developed measures of AP not used in this study, such as adaptive speech-in-noise tests instead of set noise levels and alternative tests using non-linguistic stimuli, might have yielded different results. Future studies should address these limitations and include these developments in the investigation of this population.

## *5* Conclusion

Through parental report, all clinical groups were perceived as exhibiting listening difficulties. The children diagnosed with LI and LD were found to perform significantly weaker on all AP subtests using linguistic stimuli. The children with ADHD exhibited fewer difficulties. While this group performed poorly in the DDTs, no difficulties were evident in the NWRT(n). No significant differences emerged between the TD and clinical groups on tasks using non-linguistic stimuli. This possibly suggests that the listening difficulties exhibited in Maltese children diagnosed with LI, LD and ADHD are mainly specific to linguistic stimuli. However, it would be interesting to carry out further research using other available AP tools to strengthen these claims or otherwise.

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## *8* Conflicts of interest

The authors report no conflicts of interest.

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## Appendix A

## QUESTIONNAIRE OF (CENTRAL) AUDITORY PROCESSING

Date:____________

Child's Date of Birth: _____________

Age of Child at testing: ______________

**In each of the 25 statements circle YES or NO, or a number from 1 to 5 according to how relevant each statement is to you (1 = not relevant to 5 = very relevant).**

***1*** **The child suffers, or suffered in the past, from ear problems. (Ear problems include: ear infection, earaches, draining ears, medicine taken for ear problems, fluid behind the ear drum, holes in the eardrum, glue ear.)**

| | |
|---|---|
| YES | NO |

If YES, please describe briefly: ________________________________

***2*** **The child participates or participated in special class(es) or therapies.**

| | |
|---|---|
| YES | NO |

If YES, please describe briefly: ________________________________

***3*** **The child has been diagnosed with a language impairment, dyslexia, autism or ADHD (attention-deficit/hyperactivity disorder).**

| | |
|---|---|
| YES | NO |

If YES, please describe briefly: ________________________________

***4*** **The child has suffered from a head injury or epilepsy.**

| | |
|---|---|
| YES | NO |

If YES, please describe briefly: ________________________________

***5*** **The child was born prematurely.**

| | |
|---|---|
| YES | NO |

If YES, please describe briefly: ____________________

***6*** **The child finds difficulty in listening to speech and understanding it.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***7*** **The child is sensitive to loud sounds.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***8*** **The child gets distracted in noisy places.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***9*** **The child finds difficulty in following and/or understanding television programmes.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***10*** **The child tends to increase the volume of television or audio equipment when listening.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***11*** **The child finds difficulty in following directions with multiple steps.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***12*** **The child seems to be a restless person, who finds great difficulty in keeping still.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***13*** **The child finds difficulty in attending to a task.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***14*** **The child is easily distracted.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***15*** **The child can be forgetful, specifically for spoken information.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***16*** **In conversation, the child often asks people to repeat themselves.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***17*** **The child prefers solitary activities to social activities.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***18*** **The child often finds him/herself unable to keep to task deadlines.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

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

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***20*** **The child has organisational difficulties that cause problems.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***21*** **The child tends to shy away from class discussions.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***22*** **The child finds difficulty in following long conversations.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***23*** **The child finds his/her telephone conversations frustrating.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***24*** **The child finds difficulty in taking notes in class.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***25*** **The child finds difficulty in dividing his/her attention.**

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Which language/s does your child feel most comfortable speaking?**

English ☐ Maltese ☐ Both ☐