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Research paper

AUDITORY TEMPORAL ORDER AND RESOLUTION IN YOUNGER AND OLDER MALTESE ADULTS

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Abstract. Recent studies are accruing support for the existence of auditory processing disorder in adults as a multifactorial condition underlying alterations in the auditory mechanisms and the brain. However, local research that evaluates age-related changes in temporal order and resolution is still very limited. This paper explores age-related differences on non-speech measures of temporal order and resolution by investigating the performance of younger and older Maltese adults on four tests of temporal processing. The study also compares the four measures of temporal processing and explores their relationship. Sixteen younger adults (YA) aged between 18 and 25 years and 10 older adults (OA) aged between 60 and 74 years participated in the study. Temporal ordering, as measured by the Duration Pattern Test (DPT) and the Frequency Pattern Test (FPT), and temporal resolution, as measured by the Random Gap Detection Test (RGDT) and the Gaps-in-Noise Test (GIN), were evaluated. Results indicated that in comparison to OA, YA performed significantly better in all four tests. Thus, the OA group required more time to identify temporal changes in a stream of sound and were less able to label patterns of duration and frequency. With regards to the comparison between measures, while a statistically significant difference between the two tests of temporal resolution emerged, no significant difference between temporal order tests was revealed. A negative correlation between temporal order and resolution was established, indicating that a greater percentage of correct responses on temporal order tests was related to shorter gap detection thresholds on resolution tests. These findings tentatively suggest that the two subtypes of temporal measures may underlie common auditory processing abilities but may be influenced by the type of stimuli employed or the auditory processing mechanisms being assessed.

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1 Introduction

Aging gives rise to several changes in bodily structures and functions, including the peripheral and central auditory systems (Stach, 2008). Until recently, speech understanding difficulties in older adults (OA) have been mainly attributed to hearing loss. However, it is reported that the difficulties experienced by OA with a hearing impairment are generally greater than expected given the degree of hearing loss and that difficulties persist even after the clinical restoration of the audibility aspect of the stimuli (Humes, 2007).

A contemporary body of research suggests that speech comprehension difficulties in older adults occur primarily as a result of auditory-specific deficits and supports an auditory processing disorder hypothesis (Ross et al., 2007). On the contrary, other studies, such as that by Humes, Christopherson and Cokely (1992) report that a peripheral-distortion hypothesis and a cognitive hypothesis are also possible. While the peripheral hypothesis recognises that deteriorations in speech understanding occur secondary to a decline in hearing acuity, the cognitive hypothesis proposes that this deterioration is linked with reduced cortical functions, such as information processing and retrieval.

1.1 Auditory temporal processing

The American Speech-Language-Hearing Association (ASHA, 1996) suggests that one of the main clinical measures of auditory processing is the assessment of temporal processing (TP). TP refers to the capability of the auditory system to encode the dynamic durational features of a sound within a time interval (Musiek et al., 2005). These skills are considered a fundamental ability for the perception of verbal and non-verbal sound stimuli (Bellis, 2003). Rawool (2006) identifies four subtypes of TP: temporal resolution, temporal ordering, temporal integration and temporal masking.

Temporal resolution can be defined as the auditory system's potential to react to rapid changes in the envelope of an auditory stimulus (Shinn, Chermak & Musiek, 2009).

It includes the capability of determining differences in the durational features of acoustic signals and in the time intervals that occur between stimuli over time (John, Hall & Kreisman, 2012). This ability, which provides information about transitions between phonemes, voicing and prosody, is commonly assessed through gap detection tests (Pichora-Fuller & Singh, 2006).

Two clinical tests of temporal resolution are the Random Gap Detection Test (RGDT) (Keith, 2000) and the Gaps-In-Noise Test (GIN) (Musiek et al., 2005). The GIN and the RGDT make use of within channel signals to determine age-related changes in temporal resolution (Owens et al., 2007). Previous research indicates that the GIN and the RGDT are two practical tests of temporal resolution for both paediatric and adult populations and can identify individuals with auditory nervous system disorders (Dias et al., 2011). In these individuals, although sounds travel in the inner ear normally, deficits in the transmission of signals from the inner ear to the brain are noted.

Auditory temporal ordering refers to the ability to accurately perceive multiple auditory signals in their precise order of presentation (Pinheiro & Musiek, 1985). Since the dynamic acoustic changes in fluent speech play a facilitatory function in the extraction of meaning, temporal ordering is thought to be crucial for speech recognition (Fitzgibbons & Gordon-Salant, 1996).

Auditory temporal ordering is generally measured using pattern sequencing tests. In comparison to the detection of auditory stimuli, these tests are considered to be more complex as they assess the processes of pattern discrimination, temporal ordering and linguistic labeling (Bellis, 2003). The perception and linguistic labeling of temporal order patterns, known as interhemispheric function, involves the perception of patterns in the right hemisphere, the relaying of stimuli across the corpus callosum, and the processing of stimuli by the left hemisphere for linguistic labeling (Bellis, 2003).

Research indicates that the Frequency Patterns Test (FPT) is resistant to peripheral hearing loss as long as the stimuli are audible and is sensitive to lesions of the cerebrum, the corpus callosum and the brainstem (Bamiou et al., 2006; Humes, Coughlin & Talley, 1996). The Duration Patterns Test (DPT) also assesses the processes of duration discrimination, temporal ordering and linguistic labeling (Pinheiro & Musiek, 1985) and is sensitive to cerebral lesions (Musiek, Baran & Pinheiro, 1994). Bellis (2003) argues that the DPT is a more difficult task than the FPT. In fact, at all ages, normal cut-off scores are lower for the DPT than for the FPT.

1.2 Age-related changes in temporal processing

Apart from the recognised decline in hearing acuity, the occurrence of additional age-related auditory deficits has been less well established (Parthasarathy, Cunningham & Bartlett, 2010). This is further complicated by the fact that auditory processing difficulties generally co-occur with deteriorations in memory, cognition and vision, ultimately amplifying the effects of the auditory deficits.

When compared to younger adults (YA), OA generally demonstrate significantly longer gap detection thresholds, resulting in poorer performance (Lister, Roberts & Lister, 2011). This age-related decline in temporal resolution is often associated with changes in the central nervous system, including alterations in the recovery from adaptation of eight-nerve fibres (Schneider & Hamstra, 1999) and deteriorations in neural synchrony and inhibition (Alain et al., 2004)

Although it is generally difficult to isolate the effects of hearing impairment, decreased TP in OA has been corroborated utilising various temporal paradigms (Snell & Frisina, 2000). Research on groups of age-matched OA with and without hearing loss and groups of YA confirmed that the contribution of hearing loss on temporal resolution is minimal when compared to the effect of age (Fitzgibbons & Gordon-Salant, 1995; Gordon-Salant & Fitzgibbons, 1993; Schneider et al., 1994). Similarly, a study by Fitzgibbons, Gordon-Salant and Friedman (2006) has shown that older listeners are less able to discriminate changes in duration within uniform and non-uniform tonal sequences.

Few studies have utilised non-speech measures to evaluate age-related changes in auditory processing. Besides, to date, the influence of aging on TP has not been investigated in the Maltese context. Taking the above into consideration, the main aim of this study is to investigate the possible age-related differences in temporal order and resolution in younger and older Maltese adults.

This study aims to investigate the following research questions:

(1) Is there a significant difference between the temporal order scores of YA and OA?

(2) Is there a significant difference between the temporal resolution scores of the two groups?

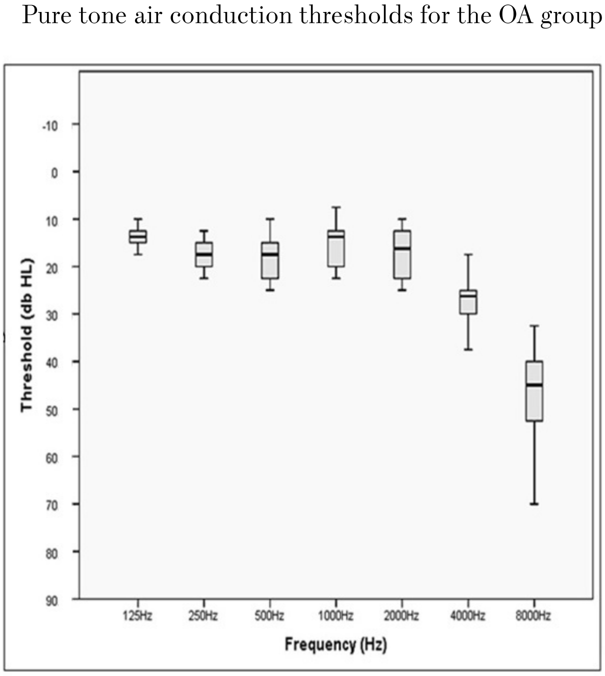
(3) Is there a correlation between the different TP measures?

2 Methods

Data collection focused on two specific groups of adults to identify whether scores on TP tests, the dependent variables, were significantly influenced by age, the independent variable.

2.1 Participants

A total of 30 individuals were recruited for the study. However, four individuals were rejected as they did not meet the subject inclusion criteria. Apart from (1) the specific age ranges and (2) the defined pure-tone hearing thresholds, participants in both groups were required to exhibit (3) “type A’’ tympanometric curves; (4) no significant interaural asymmetry (air conduction threshold differences not greater than 15 dB at two or more frequencies); (5) a score greater than or equal to 23 on the Montreal Cognitive Assessment-



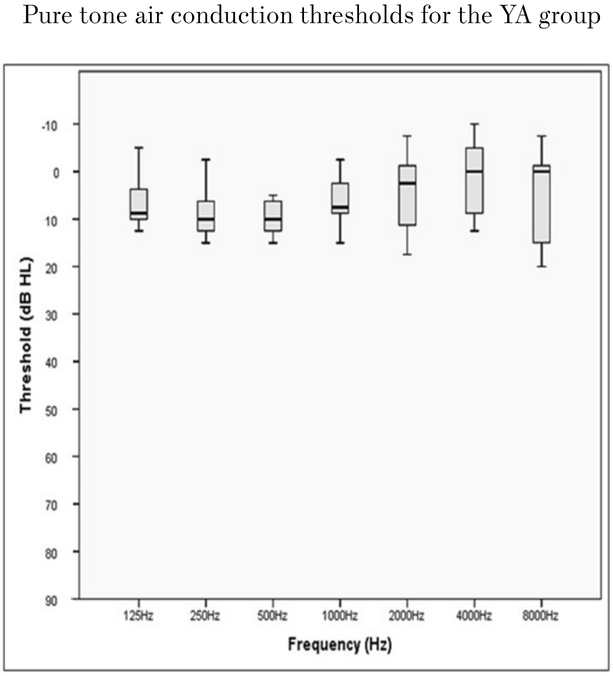


Figure 1. Mean between ears hearing thresholds of the YA and the OA groups

Maltese (MoCA-M) (Vella, 2012) and (6) negative histories for otologic, audiologic and neurologic involvement.

Participants were divided into two groups according to their age. One group, designated as the YA group, consisted of 16 young individuals, eight males and eight females (mean age = 21 years, range 18-25 years) with normal pure-tone air conduction thresholds better than or equal to 25 dB HL (hearing thresholds in decibels) from 125 to 8000 Hz.

The second group, was designated as the OA group and consisted of four male and six female adults (mean age = 65.5 years, range 60-74 years). Since adults aged 60 years or older may suffer from hearing loss (Parham et al., 2011), pure-tone air conduction thresholds for OA were defined as better than or equal to 25 dB from 125 to 2000Hz. Nevertheless, their higher frequencies (4000 Hz – 8000Hz) were still measured in an attempt to reach close matching between the two groups. The mean hearing threshold for each frequency was calculated by averaging the right and left ear pure-tone thresholds. Figure 1 displays box plots illustrating the mean between ears hearing thresholds of the YA and OA groups.

2.2 Procedure

All testing procedures were conducted by the first author at the Teaching and Research Clinic of the Department of Communication Therapy, Faculty of Health Sciences at the University of Malta. To minimise external noise, all measurements were made in a sound-treated room. Participants who confirmed their participation attended a one and a half hour clinical session. An adapted version of the Questionnaire of (Central) Auditory Processing (QCAP; Tabone, n.d.), a cognitive screen and an audiometric evaluation were completed to confirm participants' eligibility for participation. To minimise the influence of confounding variables which could compromise the testing results, the presence of medical conditions or factors that may give rise to auditory processing deficits were ruled out. Consequently, if all established criteria were met, four auditory TP tests were administered.

2.2.1 Auditory Processing Disorder questionnaire

Auditory Processing Disorder (APD) generally co-occurs with other medical, psychological and behavioural conditions that can significantly compromise test results (Baran, 2007). Through the QCAP adaptation, the occurrence of difficulties associated with APD was identified.

2.2.2 Cognitive assessment

A cognitive evaluation was included in the study to ensure that the performance on the TP tests was not influenced by the presence of cognitive impairment. The Montreal Cognitive Assessment (MoCA) is a cognitive test designed to detect mild cognitive impairment and Alzheimer's disease (Nasreddine et al., 2005). Its Maltese version, the MoCA-M, has shown that at the proposed cut-off score of 23, the test has optimal sensitivity (77.1%) and specificity (70.7%) (Vella, 2012). Based on Vella's findings, it was designated that participants needed to obtain a score greater than or equal to 23 to pass the cognitive screen.

2.2.3 Peripheral audiometric assessment

Initially, all participants underwent an otoscopic examination that was carried out by the first author under the supervision of the second author, a qualified audiologist. Two other audiometric assessments were conducted on all participants to determine their hearing status: (i) an immittance test and (ii) pure tone air conduction audiometry (PTA). Tympanometry results using an Interacoustics Impedance Audiometer AT235 H were considered normal if they reflected a peak compliance of 0.3 to 1.4 cm^3/ml at or near atmospheric pressure + 50 to − 150 daPa.

An Interacoustics AC33 Clinical Audiometer, equipped with calibrated Telephonics TDH-50P supra-aural headphones, was utilised to measure participants' pure-tone air conduction thresholds. Ballpark threshold estimates were completed using the contemporary American National Standards Institute (ANSI) (2004) and ASHA (2005) guidelines.

2.3 Auditory temporal processing tests

The tests of TP were presented using the same audiometer utilised for the PTA. Test stimuli were presented at 50 dB SL (sensation level) above the participants' pure tone average of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. To prevent any order effect from occurring test order of ears and presentation of test sequences were randomised throughout data collection.

The RGDT includes four subtests of tonal stimuli at frequencies of 500, 1000, 2000 and 4000 Hz and a click subtest. Each subtest comprises a total of nine tonal stimuli with a random interstimulus interval ranging from 0 to 40ms. The tonal and click stimuli were presented binaurally and participants responded to each stimulus by indicating whether they had heard one or two tones. A gap detection threshold (GDT) was obtained for each of the subtests. For tones, the GDT was averaged across the four frequencies to determine the composite GDT.

The GIN includes four tests lists of 60 gaps each (Musiek et al., 2005). Each test item includes a 6-second broadband noise segment containing between zero and three silent gaps. Six segments for each of the 10 gap durations (2, 3, 4, 5, 6, 8, 10, 12, 15 and 20 ms) are included in all lists.

Since the test provides similar inter-list results (Samelli & Schocat, 2008), one list was administered to each ear for a total of two lists. Participants were requested to indicate the number of gaps present for each test item. For the purpose of comparison with random gap detection, only the approximate gap threshold (ATh) was determined. This was based on the shortest gap duration correctly identified in at least four of the six gap occurrences (Musiek et al., 2005).

The DPT is composed of a set of three-tone sequences of 1000 Hz tones of varying patterns of duration. The tones are either long (L), 500ms, or short (S), 200ms. Six different sequences are used in the test: LLS, LSL, LSS, SLS, SLL and SSL. Thirty three three-tone sequences were presented monaurally to each ear for a total of 66 sequences. Participants were requested to respond to each sequence by linguistically labeling, in terms of duration, the pattern of each three-tone sequence. The score was the percentage of correctly heard sequences.

The FPT is a temporal ordering test similar to the DPT in terms of administration and scoring. The only difference is that in the FPT, the factor to be identified is frequency and not duration. Each test item consists of a three-tone sequence consisting of low (Lo) (880 Hz) and high (H) (1430 Hz) tone bursts. Six possible combinations of sequences are available in the test: HHLo, HLoH, HLoLo, LoHLo, LoHH and LoLoH. Thirty patterns were presented monaurally to each ear for a total of 60 patterns**.** After hearing each sequence, participants were requested to report each pattern as they heard it. The number of correct responses was counted and converted to percentage correct.

2.4 Ethical Considerations

Ethical approval for the present study was obtained from the Faculty and University Research Ethics Committees of the University of Malta (reference number 023/2013). An informed consent document was signed by the participants prior to their participation in the study. Moreover, to ascertain confidentiality of subjects, all gathered data were anonymised by implementing unique subject identifiers.

3 Results

This section presents the results obtained by the YA and OA groups for the four TP tests and the relationship between the different measures used in the study. A Shapiro-Wilk test was used to determine whether the data in the study followed a normal distribution. Since the test results indicated that the data did not follow a normal distribution, non-parametric statistics (Shapiro & Wilk, 1965) were used in the current study. The Mann-Whitney U test was used to compare differences in TP test scores between the two groups and Spearman's rank-order correlations were used to evaluate the relationship between scores on the TP tests.

3.1 Performance of groups on the Random Gap Detection Test (RGDT), Gaps-in-Noise Test (GIN), Duration Patterns Test (DPT) and Frequency Patterns Test (FPT)

Table 1 presents a summary of the results obtained from the RGDT for both groups. Review of the data shows that when compared to the OA group, YA gap detection thresholds were lower. For both tones and click stimuli, the difference in performance between the two groups was found to be statistically significant (500 Hz [U = 20.50, p = 0.001]; 1000 Hz [U = 7.00, p < 0.001]; 2000 Hz [U = 5.00, p <.0.001]; 4000Hz [U = 0.00, p < 0.001]; composite tones [U = 0.00; p < 0.001; clicks [U = 12.00, p < 0.001). It can be deduced that the older group performed significantly worse when compared to the younger group.

Table 1. Summary of results obtained from the RGDT for both the YA and OA groups

	Group	Mean	Median	Standard deviation	Statistical significance (p, U)
RGDT					
500 Hz	YA	8.69	10.00	3.88	$p = 0.001$
	OA	17.50	20.00	6.35	$U = 20.50$
1000 Hz	YA	7.94	10.00	3.38	$p < 0.001$
	OA	18.00	17.50	5.37	$U = 7.00$
2000 Hz	YA	7.94	10.00	2.84	$p < 0.001$
	OA	21.50	22.50	8.51	$U = 5.00$
4000 Hz	YA	6.25	5.00	2.24	$p < 0.001$
	OA	18.50	20.00	3.37	$U = 0.00$
Composite GDT-tones	YA	7.73	7.50	2.27	$p < 0.001$
	OA	18.88	18.13	4.98	$U = 0.00$
GDT-clicks	YA	6.75	7.50	3.53	$p < 0.001$
	OA	16.50	15.00	6.26	$U = 12.00$

The distribution of GIN scores for the two groups is presented in Table 2. A Wilcoxon signed-rank test showed no significant difference between the participants' right and left approximate ATh median scores ($z = -0.24$, $p = 0.981$). Since no significant differences were seen between the right and left ears, scores obtained for each ear were collapsed together as between ear ATh scores.

Table 2. Summary of cores obtained from the GIN for the YA and OA groups

	Group	Mean	Median	Standard deviation	Statistical significance (p, U)
GIN					
Right ear	YA	4.31	4.00	0.79	$p < 0.001$
	OA	7.70	8.00	2.50	$U = 14.50$
Left ear	YA	4.44	4.00	1.31	$p < 0.001$
	OA	7.60	8.00	2.07	$U = 16.50$
Between ear	YA	4.38	4.00	0.85	$p < 0.001$
	OA	7.65	7.50	2.16	$U = 12.00$

When compared to the ATh scores of the YA group, the scores of the OA group were found to be considerably higher. This difference between the two groups was found to be statistically significant ($U = 12.00$, $p < 0.001$). When compared to the YA group, the OA group demonstrated a significantly poorer performance on the GIN test.

Table 3 presents the DPT scores for both groups of participants. When compared to the younger adult group, the older adult group obtained a lower percentage correct for the right ear, left ear and between ear scores. A statistically significant difference between the percentage correct scores of the two groups was deduced (right ear [$U = 12.50$, $p < 0.001$]; left ear [$U = 28.00$, $p = 0.005$]; between ear [$U = 16.00$, $p < 0.001$]). When compared to the YA group, the OA group demonstrated a significantly poorer performance on this test.

Table 3. Summary of scores obtained from the DPT for the YA and OA groups

	Group	Mean	Median	Standard deviation	Statistical significance (p, U)
DPT					
Right ear	YA	90.91	90.90	7.59	$p < 0.001$
	OA	65.14	65.10	17.34	$U = 12.50$
Left ear	YA	87.30	89.40	11.36	$p = 0.005$
	OA	65.73	60.59	18.91	$U = 28.00$
Between ear	YA	88.94	91.50	8.86	$p < 0.001$
	OA	65.50	66.00	17.07	$U = 16.00$

A summary of the distribution of scores for the FPT for the YA and OA groups is provided in Table 4. The mean between ear scores for the older group were found to be lower than the scores of the younger group by 33% (younger group: 54.60%; older group: 87.81%). The difference between the scores was found to be statistically significant ($U = 16.00$; $p < 0.001$). Hence, when compared to the younger group, the performance of the older group was significantly poorer.

Table 4. Summary of the scores obtained from the FPT for the YA and OA groups

	Group	Mean	Median	Standard deviation	Statistical significance (p, U)
FPT					
Right ear	YA	87.24	88.30	10.40	$p < 0.001$
	OA	55.98	51.65	19.37	$U = 15.50$
Left ear	YA	88.30	86.60	6.88	$p < 0.001$
	OA	53.30	48.30	21.38	$U = 12.00$
Between ear	YA	87.81	87.00	7.86	$p < 0.001$
	OA	54.60	51.00	19.73	$U = 16.00$

3.2 The relationship between temporal order and resolution

Table 5 illustrates Spearman's rank-order correlation coefficients for the scores of all participants on all test measures. A review of the data shows that the GDT-tones were positively correlated with GDT-clicks and ATh of the GIN, but were negatively correlated with the DPT and FPT. On the contrary, the DPT was positively correlated with the FPT but was negatively correlated with GDT-tones, GDT-clicks and the ATh. Except for the correlation between the DPT and GDT-clicks, which was found to be non-significant, all other correlations were found to be significant.

The DPT and FPT were measured in percentage correct scores and the GIN and RGDT were measured in the shortest duration needed to detect a brief gap. It can be indicated that as the percentage of correct responses for the temporal order tests increased, the duration necessary to detect a brief gap during the temporal resolution tests decreased.

Table 5. Spearman's rank-order correlation coefficients for the five measures of TP

		RGDT-tones	RGDT-clicks	ATh	DPT	FPT
RGDT-tones	*rs*	1.000	0.759**	0.699**	-0.640**	-0.613**
RGDT-clicks	*rs*	0.759**	1.000	0.632**	-0.387	-0.551**
ATh	*rs*	0.699**	0.632**	1.000	-0.568**	-0.455*
DPT	*rs*	-0.640**	-0.387	-0.568**	1.000	0.604**
FPT	*rs*	-0.613**	-0.551**	-0.455*	0.604**	1.000

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

4 Discussion

Since no local studies have been conducted on TP in adults, the current findings will be discussed in the light of former international investigations.

4.1 Age-related differences in temporal resolution

Similar to the findings of the present study, previous research employing psychoacoustic procedures has found that when compared to YA, OA display significantly elevated gap detection thresholds (Harris et al., 2012; John et al., 2012; Lister & Roberts, 2005). Musiek et al. (2005) reported a mean between ear ATh threshold of 4.85 ms on the GIN test for participants aged between 13 and 46 years. Similarly, Samelli and Schochat (2008) and Chan (2008) reported a mean between ear ATh of 4.19 ms and 4.7 ms for groups of Brazilian and Cantonese young adults respectively. These scores are in good agreement with the detection threshold of 4.38 ms achieved by the Maltese YA group in the current study. The mean between ear ATh for the OA group was found to be 7.65ms. A study by John et al. (2012) reported a between ear ATh of 6.6ms for OA with normal hearing sensitivity. This difference in scores between studies may be attributed principally to the different methodological procedures. Despite this difference in mean ATh, both studies evidenced significantly elevated ATh in the older population.

With regards to the RGDT, Keith (2000) reported a composite GDT-tones of 8ms for individuals aged between 8 and 50 years. For the younger subjects in the current study, who obtained a composite GDT-tones of 7.73 ms, scores were found to compare favourably. On the contrary, the GDT of the OA group were close to the 20 ms cut-off criterion established by Keith (2000), indicating potential TP deficits. While in the current study OA aged between 60 and 74 years obtained a mean composite GDT-tones of 18.88ms and a mean GDT-clicks of 16.50ms, Owens et al. (2007) reported a mean composite GDT for tones of 14.45 ms and a mean GDT-clicks of 12.15 ms in a group of OA aged between 50 and 67 years. This difference in scores may have occurred due to a variance in age range of the OA group in the two studies. As Keith (2000) reports, while adults aged 50 years have a mean GDT-tones of 8 ms, 60- and 70-year-old participants have a mean GDT-tones of 9 ms and 22 ms respectively.

The findings of the current study indicate that the decline in temporal resolution observed in the participants occurred primarily due to aging. This premise is grounded on three assumptions. First, a statistically significant difference on temporal resolution measures was noted between the YA and OA groups. Second, even if several participants in the OA group had high frequency sensorineural loss, the chosen auditory processing tests involved frequency regions that were relatively unaffected by this loss and audibility of non-speech stimuli was ascertained by providing stimuli at 50 dB SL. Finally, the subjects in the study were representative of cognitively healthy younger and OA.

4.2 Age-related differences in temporal order

Significant differences between the two groups were also found for the DPT and FPT. When compared to YA, OA were less able to identify and label three-tone sequences. Similar to the present study, previous research using patterning tests has reported a poorer performance for OA (Fogerty, Humes & Kewley-Port, 2010; Trainer & Trehub, 1989).

For the DPT, Musiek et al. (1990) recommended a criterion of 70% or more to rule out central auditory nervous system pathology. Based on the cut-off criterion, it can be indicated that only one out of 16 YA participants (3.85%) failed the test. The mean value of 88.94% for the YA group in the current study is consistent with the mean of 88.50% reported by Musiek et al. (1990) for a group of 50 individuals aged 19-39 years. With regards to the OA group, greater variability in scores was evidenced and five subjects (50%) failed the criterion. Consistent with this finding, Ajith and

Sangamantha (2011) reported that temporal order starts to deteriorate by the sixth decade of life.

For the FPT, Musiek et al. (1994) suggested a cut-off score of 78% for normal hearing adults. Based on this criterion, one out of the 16 participants in the YA group (3.85%) and nine out of 10 subjects in the OA group (90%) failed this criterion. Conversely, only one participant in the OA group obtained a score greater than 78%. Interestingly, in a study by Sanchez et al. (2008), OA aged between 60 to 75 years obtained a mean between ear FPT score of 67.35%. A disparity between the mean FPT scores obtained by Sanchez et al. (2008) and the current study can be noted. A plausible explanation for this inconsistency in scores is that while the former study involved 40 OA, the current study only involved 10 older adult subjects. A larger sample could have yielded more precise scores and better comparisons with other studies.

The robust nature of the age effect observed in the current study and the agreement of results with other studies indicates that aging causes changes in the temporal mechanims of the auditory system used to label sequences of sound stimuli. Nevertheless, although the effects of age on performance have been documented, the cause of this decrease in performance is still unclear (Fink, Churan & Wittmann, 2005).

4.3 The relationship between temporal resolution and temporal order measures

Spearman's rank-order correlation coefficients evidenced significant positive correlations between temporal resolution measures. A significant positive correlation was also noted between the temporal order measures. Based on these findings, it can be suggested that a better performance in one temporal subtype measure was related to a better performance in the other measures of the same TP subtype.

The negative relationship between the temporal order and resolution tests may indicate that as the time necessary to detect a brief interval decreased, the percentage correct on temporal order measures tended to increase and vice versa. Thus, it may be indicated that even if temporal resolution and temporal order employ different testing stimuli and procedures, they may underlie common auditory pathway mechanisms and assess similar auditory processing abilities.

Nevertheless, since the study involved a small sample size, a causal relationship between measures cannot be excluded. Secondly, although all four tests assessed TP and may share some common physiological and higher order cognitive processes, these different measures may still underlie different auditory processes. For instance, although both the DPT and FPT are tests of temporal order, each test can detect specific cerebral lesions which the other test cannot (Musiek et al., 1994).

4.4 Clinical implications

The age-related decline in TP observed for the OA group in this study indicates that direct skills remediation through bottom up-treatment intervention, compensatory strategies and environmental adjustments might be needed to improve speech comprehension and maximise communication (ASHA, 2005). For the speech and language pathology profession in particular, environmental adjustments to improve the listening setting may include: preferential seating for the individual to increase access to the sound signals, the use of visual aids to increase comprehension, the reduction of competing stimuli and background noise, and speaking more slowly, including more pauses and emphasising key words (ASHA, 2002; Crandell & Smaldino, 2000). Besides, the obtained results further emphasise the need for the development of technological devices that might improve the communication function and quality of life of OA with APD.

4.5 Limitations of the study

The results of the current study must be considered in the light of several limitations.

(1) The number of participants included in the study was small and so, conclusions cannot be generalised to the whole population.

(2) Although the study aimed to assess adults with normal hearing thresholds, several OA had high frequency sensorineural hearing loss. Even if audibility of stimuli was ascertained by providing the stimuli at 50 dB sensation level, an effect of the high frequency loss on the test results cannot be excluded.

(3) Despite the fact that all participants passed the cognitive screen, significant differences between the YA and the OA groups were evidenced. Particularly for the temporal order tasks, this cognitive discrepancy could have augmented the group differences in temporal order scores.

5 Conclusion

This study provided preliminary comparative data concerning age-related changes in auditory temporal order and resolution in younger and older Maltese adults. Although the relationship between aging and changes in central auditory processing remains controversial, the results of this study revealed significant differences between the two groups across all measures of TP. Consistent with the available literature, these differences suggest that age interferes with the auditory system's capability to process fluctuations in the temporal dynamics of auditory stimuli. Moreover, a correlation analysis between the different measures suggests that as the percentage of correct responses increases on the DPT and FPT, the time necessary to detect a silent gap is expected to decrease. Hence, different subtypes of TP may underlie common auditory pathways and evaluate similar auditory processing capacities.

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8 Conflicts of interest

The authors report no conflicts of interest.

References

Ajith, K. U. & Sangamanatha, K. U. (2011) Temporal processing abilities across different age groups. *Journal of the Acoustical Society of America*, 22(1)*,* pp. 5-12.

Alain, C., McDonald, K. L., Ostroff, J. M, & Schneider, B. (2004) Aging: a switch from automatic to controlled processing of sounds? *Psychological Aging,* 19*,* pp. 125–133.

American National Standards Institute (ANSI) (2004) *American National Standard Specification for Audiometers*. New York: ANSI.

American Speech-Language-Hearing Association (ASHA) (1996) Central auditory processing: current status of research and implications for clinical practice. *American Journal of Audiology*, 5, pp. 41-54.

American Speech-Language-Hearing Association (ASHA) (2002) *Appropriate school facilities for students with speech-language-hearing disorders:* Technical *report*. Available from http://www.asha.org/policy/. [Accessed 15th November 2016].

American-Speech-Language-Hearing Association (ASHA) (2005) (*Central) Auditory Processing Disorders: Technical report*. [Online] Available from http://www.asha.org/policy/TR2005-00043/. [Accessed 1st November 2016].

Bamiou, D., Musiek, F., Stow, I., Stevens, J., Cipolotti, L., Brown, M. & Luxon, L. (2006) Auditory temporal processing deficits in patients with insular stroke. *Neurology,* 67(4), pp. 614-619.

Baran, J. A., & Musiek, F. E. (1999) Behavioural assessment of the central auditory nervous system. In F. E. Musiek & W. F. Rintelmann (Eds) *Contemporary Perspectives in Hearing Assessment.* (pp. 375-413). Needham Heights: Allyn and Bacon.

Bellis, T. J. (2003) *Assessment and Management of Central Auditory Processing Disorders in the Educational Setting: From science to practice (2nd ed.).* Clifton Park, NY: Thomson Learning Inc.

Chan, W. A. (2008) *Gaps-in-Noise Test: Norms for Cantonese adults in Hong Kong*. Unpublished Masters dissertation. University of Hong Kong.

Crandell, C. & Smaldino, J. (2005) Classroom acoustics for children with normal hearing and with hearing impairment. *Language, Speech, and Hearing Services in Schools,* 31, pp. 362-370.

Dias, K. Z., Jutras, B., Acrani, I. O. & Pereira, L. D. (2012) Random gap detection test (RGDT) performance of individuals with central auditory processing disorders from 5 to 25 years of age. *International Journal of Pediatric Otorhinolaryngology,* 76, pp. 174-178.

Fink, M., Churan, J. & Wittmann, M. (2005) Assessment of auditory temporal-order thresholds - a comparison of different measurements procedures and the influence of age and gender. *Restorative Neurology and Neuroscience,* 23, pp. 281-296.

Fitzgibbons, P. J. & Gordon-Salant, S. (1995) Age effects on duration discrimination with simple and complex stimuli. *Journal of the Acoustical Society of America*, 98(6), pp. 3140– 3145.

Fitzgibbons, P. J. & Gordon-Salant, S. (1996) Auditory temporal processing in elderly listeners. *Journal of the American Academy of Audiology*, *7,* pp. 183-189.

Fitzgibbons, P., Gordon-Salant, S. & Friedman, S. (2006) Effects of age and sequence presentation rate on temporal order recognition. *Journal of the Acoustical Society of America,* 120, pp. 991-999.

Fogerty, D., Humes, L. E. & Kewley-Port, D. (2010) Auditory temporal-order processing of vowel sequences by young and elderly listeners. *The Journal of the Acoustical Society of America,* 127, pp. 2509-520.

Gordon-Salant, S. & Fitzgibbons, P. J. (1993) Temporal factors and speech recognition performance in young and elderly listeners. *Journal of Speech and Hearing Research*, 36, pp. 1276-1285.

Harris, K. C., Sara, W., Eckert, M. A. & Dubno, J. R. (2012) Human evoked cortical activity to silent gaps in noise. *Ear and Hearing,* 33(3), pp. 330-339.

Humes, L. E. (2007) The contributions of audibility and cognitive factors to the benefit provided by amplified speech to older adults. *Journal of the American Academy of Audiology,* 18, pp. 590-603.

Humes, L. E., Coughlin, M. & Talley, L. (1996) Evaluation of the use of a new compact disc for auditory perceptual assessment in the elderly. *Journal of the American Academy of Audiology*, *7,* pp. 419-427.

Humes, L. E., Christopherson, L. A. and Cokely, C. G. (1992) Central auditory processing disorders in the elderly: fact or fiction? In J. Katz, N. Stecker & D. Henderson (Eds) *Central Auditory Processing: A transdisciplinary view* (pp.141-150). Philadelphia: BC Decker.

John, A. B., Hall, J. W. & Kreisman, B. M. (2012) Effects of advancing age and hearing loss on gaps-in-noise test performance. *American Journal of Audiology,* 21, pp. 242-250.

Keith, R. W. (2000. *Random Gap Detection Test (RGDT).* St. Louis, MO: Auditec.

Lister, J. J. & Roberts, R. A. (2005) Effects of age and hearing loss on gap detection and the precedence effect: narrow-band stimuli. *Journal of Speech, Language and Hearing Research,* 48(2), pp. 482–493.

Lister, J. J., Roberts, R. A. & Lister, F. (2011) An adaptive clinical test of temporal resolution: age effects. *International Journal of Audiology,* 50(6), pp. 367-374.

Musiek, F. E, Baran, J. A. & Pinheiro, M. L. (1994) *Neuroaudiology Case Studies.* San Diego, CA: Singular Publishing Group.

Musiek, F. E., Bromley, M., Roberts, D. & Lamb, L. (1990) Improvements of central auditory function after partial temporal lobectomy in a patient with seizure disorder. *Journal of the American Academy of Audiology,* 1(3), pp. 146-150.

Musiek, F., Shinn. J., Jirsa, B., Bamiou, D., Baran, J. & Zaidan, E. (2005) GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear & Hearing,* 26, pp. 608–618.

Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L. & Chertkow, H. (2005) The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society,* 53(4), pp. 695-699.

Owens, D., Campbell, P. E., Liddell, A., DePlacido, C. & Wolters, M. (2007) *Random Gap Detection Testing: A useful measure of auditory processing in an aging population?* [Online] *Available from* http://www.cs.stir.ac.uk/~kjt/research/match/resources/documents/efas07- owens.pdf. [Accessed 3rd November 2016].

Parham, K., McKinnon, B. J., Eibling, D. & Gates, G. A. (2011) Challenges and opportunities in presbycusis. *Otolaryngology - Head and Neck Surgery,* 144(4), pp. 491-495.

Parthasarathy, A., Cunningham, P. A. & Bartlett, E. L. (2010) Age-related differences in auditory processing as assessed by amplitude-modulation following responses in quiet and in noise. *Frontiers in Aging Neuroscience,* 2, pp. 1-10.

Pichora-Fuller, M. K. & Singh, G. (2006) Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiological rehabilitation. *Trends in Amplification,* 10, pp. 29-59.

Pinheiro, M. L. & Musiek, F. E. (1985) Sequencing and temporal ordering in the auditory system. In F. E. Musiek & M. L. Pinheiro (Eds) *Assessment of Central Auditory Dysfunction: Foundations and clinical correlates* (pp. 219–238). Baltimore: Williams & Wilkins.

Rawool, V. W. (2006) A temporal processing primer; Part 1: Defining key concepts in temporal processing. *Hearing Review,*13, pp. 30-34.

Ross, B., Fujioka, T., Tremblay, K. L. & Picton T. W. (2007) Aging in binaural hearing begins in mid-life: evidence from cortical auditory evoked responses to changes in interaural phase. *The Journal of Neuroscience,* 27(42), pp. 11172-11178.

Samelli, A. G. & Schochat, E. (2008) Study of the right ear advantage on gap detection tests. *Brazilian Journal of Otorhinolaryngology,* 74(2), pp. 235-240.

Sanchez, M. L., Barbosa Nunes, F., Barros, F., Ganança Malavasi, M. & Caovilla, H. H. (2008) Auditory processing assessment in older people with no report of hearing disability. *Brazilian Journal of Otorhinolaryngology* 74(6), pp. 896-902.

Shapiro, S. & Wilk, M. B. (1965) An analysis of variance for normality (complete samples). *Biometrika,* 52, pp. 591-611.

Schneider, B. A. & Hamstra, S. J. (1999) Gap detection thresholds as a function of tonal duration for younger and older listeners. *Journal of the Acoustical Society of America*, 106(1), pp. 371-380.

Schneider, B. A., Pichora-Fuller, M. K., Kowalchuk, D. & Lamb, M. (1994) Gap detection and the precedence effect in young and old adults. *Journal of the Acoustical Society of America,* 95, pp. 980-991.

Shinn, J. B., Chermak, G. D. & Musiek, F. E. (2009) GIN (Gaps-In-Noise) Performance in the pediatric population. *Journal of the American Academy of Audiology,* 20(4), pp. 229-238.

Snell, K. & Frisina, R. D. (2000) Relationships among age-related differences in gap detection and speech perception. *Journal of the Acoustical Society of America,* 107, pp. 1615-1626.

Stach, B. (2008) *Clinical Audiology: An introduction.* NY: Delmar Cengage Learning.

Tabone, N. (n.d.). *Questionnaire of (Central) Auditory Processing.* Unpublished questionnaire. University of Malta.

Trainor L. J. & Trehub, S. E. (1989) Aging and auditory temporal sequencing: ordering the elements of repeating tone patterns. *Perception and Psychophysics,* 45, pp. 417-426.

Vella, R. (2012) *The Montreal Cognitive Assessment – Maltese: Assessing validity and reliability.* Unpublished Masters Dissertation. University of Malta.