Research paper

INVESTIGATING THE EFFECT OF LONG-TERM MUSICAL EXPERIENCE ON THE AUDITORY PROCESSING SKILLS OF YOUNG MALTESE ADULTS

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Abstract. Learning and practising a musical instrument has recently been thought to 'train' the brain into processing sound in a more refined manner.As a result, musicians experiencing consistent exposure to musical practice have been suspected to have superior auditory processing skills. This study aimed to investigate this phenomenon within the Maltese context, by testing two cohorts of young Maltese adults. Participants in the musician cohort experienced consistent musical training throughout their lifetime, while those in the non-musician cohort did not have a history of musical training. A total of 24 Maltese speakers (14 musicians and 10 non-musicians) of ages ranging between 19 and 31 years were tested for Frequency Discrimination (FD), Duration Discrimination (DD), Temporal Resolution (TR) and speech-in-noise recognition. The main outcomes yielded by each cohort were compared and analysed statistically. In comparison to the non-musician cohort, the musicians performed in a slightly better manner throughout testing. Statistical superiority was surprisingly only present in the FD test. Although musicians displayed a degree of superiority in performance on the other tests, differences in mean scores were not statistically significant. The results yielded by this investigation are to a degree coherent with implications of previous research, in that the effect of long-term musical experience on the trained cohort manifested itself in a slight superiority in performance on auditory processing tasks. However, this difference in scoring was not prominent enough to be statistically significant.

Keywords: auditory processing, musical training, malleability, auditory system

1 Introduction

Auditory processing shapes the way meaningful acoustic information, including speech sounds, is extracted from complex acoustic stimuli (Banai & Kraus, 2007). The processing of auditory information is said to have an intricate plasticity which may be

adaptable to experience, training and environmental change (Zendel & Alain, 2012). Research has suggested that acoustic training results in functional and structural changes in the auditory system (Hannon & Trainor, 2007). Furthermore, researchers have hypothesised that as physical training shapes one's physical fitness, music may shape 'auditory fitness' (Chandrasekaran & Kraus, 2010).

Musical training involves constant judgement of acoustic sounds according to their frequency, timing and overall quality. These factors happen to be the basic components by which sounds, ranging from meaningless tones to speech sounds, are processed (Kraus et al., 2009). Musical training could therefore be a tool which 'sharpens' the auditory processing system, with trained musicians excelling in auditory processing tasks due to their expertise within the area.

The current study investigates the effects of long-term musical training in Maltese adults. It aims to identify discrepancies, if any, in the performance of long-term musicians and non-musicians aged 19 to 31 in Frequency Discrimination (FD), Duration Discrimination (DD), Temporal Resolution (TR) and speech-in-noise recognition.

2 Methods

Ethical approval for this research study was obtained from the University of Malta Research Ethics Committee. Prior to testing, the participants were presented with Maltese and English versions of an information sheet on the course of the assessments and what their participation in the investigation would entail. The information sheet also described the purpose of the research and specified the individual subtests to be administered, while assuring that confidentiality of the participants would be respected during and following completion of the study.

2.1 Participant recruitment

The selection criteria for the study participants were as follows:

- the participant had to be a native Maltese speaker
- the participant had to be between 19 and 31 years of age
- the participant had to have a normal range of hearing (0 dB to 25 dB)
- the participant had no history of Auditory Processing Disorder (APD).

The subjects selected for this study were divided into two cohorts and referred to as musicians and non-musicians. Subjects assigned to the musician cohort were:

- individuals whose musical experience started by the age of 9 and had been consistent throughout their lifetime
- individuals who engaged in musical practice for three or more times a week within the previous three years.

Individuals who failed to meet any of these criteria were neither classified as a musician nor as a non-musician. The non-musician cohort was made up of individuals meeting the general criteria, but completely lacking a history of musical training.

A screening checklist was given to individuals who gave their consent for participation. This tool, adapted from a checklist for children with auditory processing issues (Calleja, n.d.), was used as a means of deciding whether the participants showed behaviours related to APD. Individuals showing a significant number of APD traits were not included in the research sample.

An Interacoustics®AC33 clinical audiometer was used to determine the participants' hearing threshold and to ensure that hearing was of a normal range (0 dB to 25 dB). Air-conduction testing was carried out, involving presentation of the pure tone to each ear independently through specialised headphones (Aras, 2003).

2.2   Pilot study

During the pilot study phase, two individuals who satisfied the general criteria, but could not be classified in any of the subject cohorts, were tested. Following the pilot study, amendments to the environment in which the tests were carried out were made. The air-conditioning system was switched off during testing, eliminating disturbances brought about by background noise.

2.3   Data collection

Of the 24 participants who satisfied the general criteria, 14 subjects were grouped in the musician cohort, whilst 10 subjects were grouped in the non-musician cohort. The data collection phase required the use of a desktop computer which presented the auditory stimuli, the Interacoustics®AC33 clinical audiometer through which the stimuli were presented and specialised headphones which delivered the sound stimuli to the participant. Selected areas of the domain of auditory processing were assessed for each participant, as shown in Table 1.

2.3.1   The Frequency Pattern Test (FPT)

The Frequency Pattern Test (FPT) is a central auditory processing test assessing FD (Musiek, 1994). Participants were exposed to a series of three tones through headphones, with each tone having a 200 ms duration with an inter-stimulus interval of 150 ms. Each tone could be of a high pitch (1122 Hz) or a low pitch (880 Hz). This test was administered at a 50 dB level, presenting 30 stimuli to each ear. Participants were exposed to five practice items prior to initiation of the test. Following each series of three tones, participants were asked to identify the pattern of high and low tones in the correct order through verbal responses (labelling tones as 'high' and 'low' accordingly). Inter-pattern intervals were allotted in order to provide sufficient time for a response. The total amount of correct responses was calculated.

2.3.2   The Duration Pattern Test (DPT)

During the Duration Pattern Test (DPT), each participant was exposed to a series of three pure tones at 1000 Hz which were separated by 300 ms. Each tone was either of a long (500 ms) or a short (250 ms) duration. Following each three-tone series, the participant was expected to verbally describe the sequence heard. This test was administered at 50 dB, presenting 33 three-tone series in each ear. The participant was exposed to five practice items prior to initiation of testing. Time for response was allotted between each three-tone sequence. The correct identification attempts were scored following assessment.

2.3.3   Gaps-in-Noise (GIN) Test

The Gaps-in-Noise (GIN) Test assessed the participants' TR (Prem, Shankar & Girish, 2012). Use was made of two lists (Test 2 and Test 3) which were referred to as comparable and reliable (Prem et al., 2012). One list was carried out for each ear. Each test is composed of a series of 6s noise segments. Following each white noise and silence gaps segment, participants were asked to recite the number of gaps heard. The participants' performance was scored on the GIN Score Sheet (Musiek et al., 2005).

2.3.4   The Test for Non-Word Repetition in Noise: Maltese and English versions

During both language versions of the Non-Word Repetition in Noise Test, the participants were asked to listen to an audio-recording of non-words at an intensity of 50 dB HL and a signal-to-noise ratio of 5 dB. The participants were asked to repeat the non-word heard. This procedure was used for both English and Maltese non-words. The respective amounts of errors made in both tests were noted and classified as omission, articulation or reversal errors.

2.4   Data analysis

The IBM SPSS Statistics software was used for statistical analysis of the quantitative data collected. An expert statistician assisted statistical analysis.

The Kolmogorov-Smirnov Test was used to determine whether the mean scores obtained during testing had a normal distribution. The Null Hypothesis (H_0) for the Kolmogorov-Smirnov Test specifies that the score distribution is normal and is accepted if the p-value exceeds the 0.05 level of significance. The Alternate Hypothesis (H_1) specifies that the scores achieved have a skewed, non-normal distribution and is accepted if the p-value is less than the 0.05 criterion. The Independent Samples T-test and the Mann-Whitney Test were used to compare mean scores of two independent groups (musicians and non-musicians). For normally distributed scores, the Independent Samples T-test (parametric test) was used to compare mean scores obtained by musicians and non-musicians. The Mann-Whitney Test (non-parametric test) was used to compare mean scores when the score distribution was not normal (p-value < 0.05).

Table 1. Auditory processing skills investigated

Test	Auditory Processing Skill
The Frequency Pattern Test (FPT) (Musiek, 1994)	Frequency Discrimination (FD)
The Duration Pattern Test (DPT) (Musiek, 1994)	Duration Discrimination (DD)
The Gaps-in-Noise (GIN) Test (Musiek et al., 2005)	Temporal Resolution (TR)
Test for English Non-Word Repetition in Noise (Calleja, n.d.)	Speech-in-noise
Test for Maltese Non-Word Repetition in Noise (Calleja, n.d.)	Speech-in-noise

3 Results

Table 2 summarises the outcomes of the Kolmogorov-Smirnov Test and specifies the statistical tests used to compare mean scores obtained by the participating cohorts.

Table 3 summarises H_0 and H_1 for the tests carried out during this investigation. The p-value deduced from either the Independent Samples T-Test or the Mann-Whitney Test determined whether H_0 or H_1 was accepted. If the p-value exceeded the 0.05 criterion, H_0 was accepted. On the other hand, if the p-value was less than the 0.05 criterion, H_1 was accepted.

Table 4 summarises the results obtained following statistical analysis of the FPT scores. The mean number of correct responses made by the musician and non-musician cohorts differed significantly (H_1 was accepted), with musicians scoring an average of 59.86 responses and non-musicians scoring a mean of 53.40 from 60 possible correct responses.

Table 5 summarises the results obtained following statistical analysis of DPT scores. The average number of correct responses made by the two participating cohorts was considered to be comparable (p-value marginally exceeded the 0.05 criterion).

Table 2. Normality of distribution test outcomes and implications for statistical tests to be employed

Test	Kolmogorov-Smirnov Test outcome	Independent Samples T-Test	Mann-Whitney Test
FTP	Non-normal		√
DTP	Non-normal		√
GIN Test: List 2	Non-normal		√
GIN Test: List 3	Normal	√	
Maltese Non-Word Repetition in Noise	Normal	√	
English Non-Word Repetition in Noise	Non-normal		√

Table 3. H_0 and H_1 for the testing procedure

Test	H_0	H_1
FTP	The mean numbers of correct frequency patterns guessed by musicians and non-musicians are comparable	The mean numbers of correct frequency patterns guessed by the two groups differs significantly.
DTP	The mean numbers of correct responses made by the two cohorts during the DPT are comparable	The mean numbers of correct responses made by the two cohorts during the DPT differ considerably.
GIN Test (Lists 2 & 3)	The mean numbers of detected gaps made by the two cohorts during the GIN Test are comparable.	The mean numbers of detected gaps made by musicians and non-musicians during the GIN test differ significantly.
Test of Non-Word Repetition in Noise (Maltese & English)	The mean number of errors made by musicians and non-musicians is comparable.	The mean number of errors made by the two groups differs significantly.

Table 4. Summary of Mann-Whitney Test outcomes (Frequency Pattern Test (FPT))

Cohort	Sample Size	Mean	Std. Dev.	p-value
Musicians	14	59.86	0.535	<0.001
Non-Musicians	10	53.40	8.208	

Table 5. Summary of Mann-Whitney Test outcomes (Duration Pattern Test (DPT))

Cohort	Sample Size	Mean	Std. Dev.	p-value
Musicians	14	62.64	3.478	0.056
Non-Musicians	10	56.40	7.981	

Table 6. Summary of Mann-Whitney Test outcomes (Gaps-in-Noise (GIN) Test: List 2)

Cohort	Sample Size	Mean	Std. Dev.	p-value
Musicians	14	48.57	6.309	0.158
Non-Musicians	10	46.30	6.219	

Table 7. Summary of Independent Samples T-Test outcomes (Gaps-in-Noise (GIN) Test: List 3)

Cohort	Sample Size	Mean	Std. Dev.	p-value
Musicians	14	49.57	6.880	0.257
Non-Musicians	10	46.40	6.114	

Table 8. The Independent Samples T-Test outcomes (Non-Words in Noise: Maltese)

Cohort	Sample Size	Mean	Std. Dev.	p-value
Musicians	14	11.07	5.166	0.281
Non-Musicians	10	13.00	2.211	

Table 9. The Mann-Whitney Test outcomes (Non-words in Noise: English)

Cohort	Sample Size	Mean	Std. Dev.	p-value
Musicians	14	12.00	3.700	0.616
Non-Musicians	10	12.80	4.686	

Table 6 summarises the results obtained through statistical analysis of the scores obtained by both cohorts on List 2 of the GIN Test. H_0 for the GIN Test was accepted, deeming the mean scores obtained by the participating cohorts as comparable. The mean number of correct responses made by musicians (48.57) was only slightly higher than that achieved by non-musicians (46.30).

Table 7 summarises the results obtained following statistical analysis of the scores obtained by both cohorts on List 3 of the GIN Test. Since the p-value exceeds the 0.05 criterion, H_0 was accepted, suggesting that the mean number of correct responses was comparable.

Following completion of Lists 2 and 3, outcomes were analysed to obtain the Threshold of Gap Detection, which is the smallest time interval in which a continuous time interval is interrupted (Musiek et al., 2005). The Mann-Whitney Test accepted H_0, suggesting that the means of Threshold of Gap Detection achieved by the participating cohorts were similar. The Threshold of Gap Detection for each cohort was consistent through both lists. This is understandable since these lists are described as comparable sections of the GIN Test (Prem et al., 2012).

Table 8 summarises the results obtained following statistical analysis of the scores obtained during the Maltese Non-Word Repetition in Noise Test. Since the p-value obtained exceeded the 0.05 criterion (0.281), H_0 was accepted, verifying that the mean number of errors made by musicians and non-musicians was comparable and did not differ in a significant manner.

Table 9 summarises the results of statistical analysis of the scores obtained during the English Non-Word Repetition in Noise Test. Since the p-value exceeded the 0.05 criterion (0.616), the results achieved by musicians and non-musicians were treated as comparable since the means only differed marginally.

4   Discussion

This investigation targeted four primary areas of auditory processing: FD, DD, TR and speech-in-noise recognition. The reasoning behind the selection of these areas was based on the notion that musicians identify meaningful acoustic patterns within sound stimuli through musical practice. In the light of previous studies, it was hypothesised that musicians are more attuned to judging meaningful speech sounds in the presence of background noise (Barrett et al., 2013). Musicians were also expected to be more accustomed to identifying changes in frequency and rhythm than non-musicians (Strait et al., 2013).

Strait et al. (2013) also suggested that in long-term musicians who started musical training during their childhood (as in the case of the participating musician cohort), frequency and duration discrimination as well as gap-detection develop distinctively during neural development and combine to result in an improvement of speech-in-noise perception. The tested auditory processing skills may therefore 'co-exist', resulting in a heightened recognition of speech in background noise. The general results of this study challenge these views, since this 'superiority' of musicians was only

observed to be of a marginal nature. This slight superiority may have contributed to resilience of speech recognition in background noise, resulting in a slight advantage for musicians in the final Test of Non-Word Repetition in Noise.

4.1   Frequency Discrimination outcomes

In this investigation, the discrepancy in cohort performance was mostly evident in the FD task, which was the only tested area generating statistically significant results. FD is an auditory processing skill which forms one of the primary dimensions common throughout musical production styles (Krumhansl, 2000). It is therefore impossible to engage in musical training without practising FD skills, regardless of the instrument or musical genre practised. In fact, brain scan comparisons between musicians and non-musicians have suggested that active practising of FD skills resulted in musicians' more refined response to frequency changes during speech at a sub-cortical level (Wong et al., 2007). This 'refinery' reflected itself in the outcomes of this investigation, since musicians particularly excelled during this test by scoring a mean of 59.86 out of 60 possible correct responses whilst the non-musician cohort scored a mean of 53.40.

The outcomes of FD testing were also coherent with previous research, implying that musicians' superiority stems from the notion that musical training keeps the musician 'cognitively exposed' and 'attuned' to detect even miniscule frequency changes (Kishon-Rabin et al., 2001). This is an important factor for communication since efficient FD could enable the individual to detect meaningful pitch changes during speech, supporting 'refined' verbal comprehension (Nagle & Musiek, 2009).

The remaining outcomes yielded during this investigation were not of a statistically significant nature, potentially due to the limited sample size used for testing or the fact that differences in cohort performance were not as robust as expected. Even though marginal at instances, a discrepancy in performance was still present in the outcomes of each administered test. Comparison of test outcomes suggests agreement with the proposition that musicians exhibit an 'edge' over non-musicians in auditory processing skills (Kraus, 2011). Considering that the 'edge' exhibited was not as well-defined as expected, the outcomes challenge the idea that ongoing practice does in fact refine auditory processing skills .

4.2   Duration Discrimination outcomes

During musical performance, musicians are found to attain precise DD. A positive relationship between the ability to excel musically and the ability to discriminate duration changes has been supported by recent research deeming DD a vital attribute of distinguished musical ability (Rammsayer, Buttkus & Altenmüller, 2012). The results yielded by this study suggest that musicians were in fact slightly more proficient (62.64) than non-musicians (56.40). However, this raises the following question: if FD and DD are both vital for musical production (Krumhansl, 2000; Rammsayer et al., 2012), for what reason did the musician cohort only

perform significantly in FD testing?

Musical sounds result in a more powerful response rate than brief and abstract tones (Krumhansl, 2000). The use of brief and abstract tones during the testing procedure may have yielded results which do not fully reflect the musician cohort's potential, although brain scan research shows that a musician's brain still responded to simple artificial tones more effectively than non-musicians (Peretz & Zatorre, 2005). Using tones during this testing was considered to be beneficial, since it eliminates pre-set advantages for the musician cohort (Lim & Sinnett, 2012).

4.3   Temporal Resolution outcomes

Similar abstract stimuli were used during TR testing via the GIN Test. Although musicians detected more silent gaps than non-musicians, the discrepancy of outcomes between the participating cohorts was not statistically significant. This ultimately suggests that musicians and non-musicians do not differ significantly in their level of performance in TR tasks.

The outcomes of the current study followed the pattern of results obtained from an investigation focusing on discrepancies in TR skills using the GIN Test on a limited research sample (Martinez Monteiro et al., 2010). The resemblance between the different result sets may be attributed to the fact that both studies tested a limited sample size. Although musicians exhibited more refined skills in identifying silence gaps, the discrepancies, registered in both studies, were not statistically significant.

Outcomes for this section of testing suggested that musicians may be slightly better in TR tasks, and also exhibit a smaller gap detection threshold in comparison to non-musicians. Musicians may therefore only be able to detect a marginally smaller silence gap than non-musicians. The ability to detect smaller silence gaps indicates refined auditory acuity, which is a critical skill for accurate decoding of speech sound detection in background noise (Sangamanatha et al., 2013).

4.4   Speech-in-noise recognition

This slight 'accurate decoding' was reflected in the final test which assessed speech-in-noise recognition. This test was meant to ultimately determine which cohort would be more efficient in understanding speech in the presence of background noise. Participants were tested using non-words so as to eliminate the variability caused by guessing of words. Discrepancies were however not of a statistically significant nature. Musicians made fewer errors in comparison to non-musicians in both Maltese- and English-based non-words. This remained true to research focused on this area which suggests that following life-long training, adults experienced gains in speech-in-noise perception, whereas non-musicians experienced no such gains (Anderson et al., 2013; Strait et al., 2013; Tierney et al., 2013).

It is important to note the outcomes observed for both the Maltese- and English-based non-words achieved by both cohorts. Although musicians manifested the least amount of errors in both cases, there was a general increase in errors during the English version of the test. An explanation for this difference could be that the selection criteria required the subjects' first language (L1) to be Maltese. Previous research targeting speech-in-noise recognition in Spanish and Dutch users of English stated that the difficulty of listening to speech-in-noise is intensified when the speech is in the listeners' second language (L2) rather than their L1 (Cutler et al., 2007).

The types of errors made were divided into three categories for both L1 and L2: articulation, omission and reversal. Interestingly, although the mean numbers of errors were slightly different between languages (more errors in L2) and cohorts (superior performance by musicians), the ranking of errors seemed to be consistent in all outcomes. Errors were mainly articulation errors, followed by omission errors, with reversal errors being the rarest type of errors. The difference in types of errors, with non-musicians exhibiting a higher amount of errors, could be explained by research literature that suggests that trained musicians show more distinct neural encoding of stop consonants (Strait et al., 2013). This response corresponds to consonant-vowel transitions (Miller & Nicely, 1955), which accounted for the decrease in likelihood of errors for the musician cohort.

The musician cohort was composed of individuals who had life-long exposure to music, experiencing 'heightened stimulation' during 'sensitive periods' of development. The advantages of this exposure were observed marginally throughout the test outcomes as musicians performed in a slightly better manner than non-musicians. As implied by these outcomes, strengthened distinction of frequency, duration and temporal resolution strengthened speech-in-noise recognition (Strait et al., 2013).

Previous research suggested that refinements result in fine-tuning of acoustic features of musical sounds which can be assumed to occur equally for musical sounds and speech sounds (Chandrasekaran & Kraus, 2010) due to the overlap between processing of language and music (Chan, Ho & Cheung, 1998; Menon & Levitin, 2005; Patel, 2011; Tallal & Gaab, 2006). Due to this overlap, musical training could serve as a training ground for the development of language skills including verbal memory, verbal intelligence, attention (Chan et al., 1998; Tallal & Gaab, 2006) and literacy skills (Foregeard et al., 2008).

Music training has also been suspected to aid in refining the perception of minute acoustic differences that distinguish sounds, which may be extended to the processing of speech (Strait et al., 2013). This was supported by the outcomes of this study which highlighted musicians' superiority in speech-in-noise detection. The ability to 'rise above' background noise in speech understanding broadens the chances of the individual to succeed academically (Tierney et al., 2013). Long-term musical training equips the musician with the advantage of heightened auditory processing abilities which translate into superior speech-in-noise perception, language-related abilities and academic performances (Parbery-Clark et al., 2009; Tierney et al., 2013).

4.5   Limitations

Due to the strict nature of the subject selection criteria, the number of participants tested was rather limited. The use of smaller sample sizes may jeopardise the precision of estimates, producing a familiar decrease in statistical power as the sample decreases (Ware & Brewer, 1999). The p-value yielded through statistical analysis is heavily dependent on sample size. Seeing that the sample size for this study was limited and the scores obtained by the cohorts tested did not exhibit prominent differences, it was highly unlikely that the discrepancy between scores by musicians and non-musicians was considered significant following statistical analysis.

5   Conclusions

Since this investigation tested a limited sample size and musicians' and non-musicians' scores were only marginally different, it was challenging for this study to be significantly conclusive on the various points that surfaced following data analysis. Regardless of the fact that not all the test results were of statistical significance, this study provided insightful indications which could be a source for further research in this field.

Musicians performed better throughout the testing procedure when compared with the non-musician cohort. Although this superiority was marginal, musicians presented the hypothesised 'edge' (Kraus, 2011) over non-musicians in being successful during auditory processing tasks. The discrepancies in performances were not as significant as this study had hypothesised. However, following analysis of the data collected, it is highly likely that life-

long experience within the musical field manifested itself in refined auditory processing abilities which were exhibited throughout the course of testing.

The auditory processing skills tested, namely FD, DD, TR and speech-in-noise recognition have implications for the resilience of the individual as both a functional communicator and a successful academic being (Menon & Levitin, 2005; Patel, 2011). Musical training may thus benefit individuals not only in their auditory well-being, but also in their ability to exploit their full potential.

The indications drawn by this investigation could be further explored through a larger-scale study testing a larger sample size. Since similar studies have not been previously carried out in Malta, a similar procedure could be adopted for different age groups. Studying the effects of musical training on auditory processing skills may also be related to subsequent academic success rate. Positive findings within this area could promote musical training as a learning skill. Since this study tested limited ranges of auditory processing skills, it would also be useful to administer a full test battery across cohorts of lifelong musicians and non-musicians to gain a more holistic view of the effects of long-term musical training on auditory processing skills.

6   Funding

7   Conflicts of Interest

The authors report no conflicts of interest.

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