Speech recognition in noise and temporal resolution abilities of formally trained musicians

By Michèle Nicole Schoeman

17064041

A dissertation submitted in fulfilment of the requirements for the degree

MA Audiology

In the Department of Speech-Language Pathology and Audiology

Faculty of Humanities

University of Pretoria

Supervisors:

Prof Lidia Pottas

Prof Maggi Soer

Dr Karina C. de Sousa

October 2022

© University of Pretoria

No part of this work may be reproduced in any form or means, electronically, mechanically, by print or otherwise, without prior permission by author.

Michèle Nicole Schoeman

Department of Speech-Language Pathology and Audiology

University of Pretoria

Pretoria

South Africa

michele.mschoeman@gmail.com

© University of Pretoria

Declaration of originality

DECLARATION OF ORIGINALITY

UNIVERSITY OF PRETORIA

The **Department of Speech-Language Pathology and Audiology** places great emphasis upon integrity and ethical conduct in the preparation of all written work submitted for academic evaluation.

Academics teach you about referencing techniques and how to avoid plagiarism; it is your responsibility to act on this knowledge. If you are at any stage uncertain as to what is required, you should speak to your lecturer before any written work is submitted.

You are guilty of plagiarism if you copy something from another author's work (e.g., a book, an article or a website) without acknowledging the source and pass it off as your own. In effect you are stealing something that belongs to someone else. This is not only the case when you copy work word-for-word (verbatim) but also when you submit someone else's work in a slightly altered form (paraphrase) or use a line of argument without acknowledging it.

Students who commit plagiarism will not be given any credit for plagiarised work. The matter may also be referred to the Disciplinary Committee (Students) for a ruling. Plagiarism is regarded as a serious contravention of the University's rules and can lead to expulsion from the University.

The declaration which follows must accompany all written work submitted while you are a student of the **Department of Speech-Language Pathology and Audiology**. No written work will be accepted unless the declaration has been completed and submitted.

Full names and surname of student: **Michèle Nicole Schoeman**

Student number: **17064041**

Topic of work: **Speech recognition in noise and temporal resolution abilities of formally trained musicians.**

© University of Pretoria

Declaration

1. I understand what plagiarism is and am aware of the University's policy in this regard.
2. I declare that this **dissertation** is my own original work. Where other people's work has been used (either from a printed source, internet, or any other source), this has been properly acknowledged and referenced in accordance with departmental requirements.
3. I have not used work previously produced by another student or any other person as my own.
4. I have not allowed and will not allow anyone to copy my work with the intention of passing off as his or her own work.

27/10/2022

SIGNATURE DATE

© University of Pretoria

Acknowledgements

This research project would not have been possible without the contributions of a few individuals, whom I would like to thank:

- First and foremost, I would like to thank my Heavenly Father. He has given me the opportunity and encouragement throughout all the challenging moments of completing this dissertation. I give all the glory to Him.
- I am thankful for my family, especially my parents and brother for your unconditional love and support. Thank you for always believing in me and keeping my spirits and motivation high during this process.
- My supervisors, Prof Pottas, Prof Soer and Dr de Sousa, thank you for your assistance and guidance through this process. Thank you for providing me your knowledge and insight, so that I could complete this research project.
- I would like to thank Prof Panebianco, for inviting the music students to participate in my research study.
- Thank you to Prof Graham for assisting in the statistical data analysis. Thank you for your patience during this process and the insight that you provided.
- A sincere thank you to Mrs de Wet for her excellent Language Editing Services. Thank you for taking the time to read my manuscript thoroughly and provide constructive feedback.
- I am grateful to my fellow classmates, my friends and roommates for their continuous motivation and support during the writing and data collection procedures. You kept me grounded, focussed, and determined to continue with this dissertation.
- Thank you to all the participants that were so eager and interested to participate in my study.

© University of Pretoria

Table of Contents

Declaration of originality iii
Acknowledgements v
List of figures vii
List of tables vii
List of abbreviations ix
Abstract 1
Chapter 1: Introduction 3
Chapter 2: Methodology 8
1. Research aim 8
2. Research design 8
3. Ethical considerations 8
2.3.1 Informed consent 9
2.3.3 Protection from harm 9
2.3.4 Anticipated benefits 9
2.3.5 Plagiarism 10
4. Sampling method 10
5. Participants 10
2.5.1 Selection criteria 10
2.5.2 Material and apparatus for participant selection 11
2.5.3. Participant selection procedure 12
2.5.4 Participant description 14
2.6 Data collection 15
2.6.1 Material and apparatus for data collection 15
2.6.2 Procedures for data collection 15
2.7 Data processing and analysis procedures 18
2.8 Reliability and validity 19
Chapter 3: Research article 20
3.1. Abstract 21
3.2. Introduction 22
3.3. Materials and method 25
3.3.1. Study design and Participants 25
3.3.2. Procedures and Equipment 26
3.3.2.1.Pure tone audiometry 26

© University of Pretoria

3.3.2.2.Digits-in-noise test 26
3.3.2.3.Gaps-in-noise test 27
3.4. Statistical Analysis 28
3.5. Results 28
3.5.1. Pure tone audiometry 28
3.5.2. Digits-in-noise test 30
3.5.3. Gaps-in-noise test 31
3.6. Discussion 31
3.7. Acknowledgements 24
3.8. Data availability statement 24
3.9. References 35
Chapter 4: Discussion, clinical implications and conclusion 42
4.1. Overview of research findings 42
4.2. Clinical implications of the study 46
4.3. Critical evaluation 46
4.4. Recommendations for future research 47
4.5. Conclusion 47
References 49
List of appendices 57

List of figures

Figure 1: Mean and standard deviations of pure tone thresholds of the left ears between musicians and non-musicians 29

Figure 2: Mean and standard deviations of pure tone thresholds of the right ears between musicians and non-musicians 29

Figure 3: DIN SRT thresholds for the homphasic and antiphasic listening conditions, as well as the BILD for both musician and non-musician groups 30

List of tables

Table 1: Equipment for participant selection 11

Table 2: Equipment for data collection 15

© University of Pretoria

Table 3: GIN test means and SD of total percentage and A.th. between musicians and non-musicians ……31

© University of Pretoria

List of abbreviations

ABR:	Auditory brainstem responses
dB SPL:	Decibel sound pressure level
dB:	Decibel
DIN:	Digits-in-noise
EHF:	Extended high frequency
GIN:	Gaps-in-noise
HINT:	Hearing in noise test
Hz:	Hertz
kHz:	Kilohertz
MIHL:	Music-induced hearing loss
ms:	millisecond
NR:	No response
PTA:	Pure tone average
RGDT:	Random gap detection test
s:	second
SNR:	Signal-to-noise ratio
SRT:	Speech recognition threshold

© University of Pretoria

Abstract

UNIVERSITY OF PRETORIA

FACULTY OF HUMANITIES

DEPARTMENT OF SPEECH-LANGUAGE PATHOLOGY AND AUDIOLOGY

Initials and surname	MN Schoeman
Supervisors	Prof Lidia Pottas Prof Maggi Soer Dr Karina C. de Sousa
Title	Speech recognition in noise and temporal resolution abilities of formally trained musicians.

Abstract

Background: It has often been reported that musicians may have an advantage, or a 'musician advantage', to perceive speech in the presence of background noise. Musicians may also have improved central auditory processing skills, which may assist in better speech recognition in noise, however contradicting research has found no musician advantage in speech recognition in noise.

Aim: The aim of the current study was to compare the temporal resolution and speech recognition in noise abilities between musicians and non-musicians with normal hearing sensitivity (PTA of ≤ 15 dB HL).

Method: In this quantitative cross-sectional comparative group research study forty participants' conventional and extended high-frequency pure tone thresholds were determined using the hearTest™. The Digits-in-Noise (DIN) test was used to evaluate speech recognition in two different listening conditions, namely homophasic and antiphasic. Temporal resolution was tested using the Gaps-in-Noise (GIN) test. A binaural intelligibility-level difference (BILD) was calculated by using the two values obtained in the homophasic and antiphasic recognition in noise listening conditions.

Results: There were no differences between the groups in EHF thresholds, DIN SNR values and BILD SNR values, as well as the GIN approximate thresholds. Musicians

© University of Pretoria

presented with slightly better performances, however not significant (p > .05), in the GIN and DIN tests.

Conclusion: This study could not find significant differences in the specified auditory performances between musicians and non-musicians. The musician group, however, performed slightly better, although not significantly different, across all tests, except with the BILD results. The non-musician group performed better, although not significantly better, in the BILD test. The results of this study suggest longitudinal research in order to shed more light on discrepancies in literature.

Keywords: musicians; temporal resolution; speech recognition in noise; extended high frequencies

© University of Pretoria

Chapter 1: Introduction

One of the first signs and complaints of having a hearing loss is the difficulty of recognising speech in the presence of background noise (Smits et al., 2013; McKay, 2021). This is due to the loss of spectral and temporal information in the organs of hearing (McKay, 2021; Wolmarans et al., 2021). Speech recognition in noise is very complex. It requires not only the ability to just hear the speech, but also the ability to spatially separate noise and speech to make sense of the speech stimuli. For this to happen, an individual needs to make use of both peripheral, i.e., normal hearing, and central auditory, i.e., auditory processing, skills. Should one of these systems not be functional, the individual will struggle to hear speech stimuli in the presence of background noise.

Continuous research has been done to identify and develop new intervention methods to improve the ability to hear speech stimuli in the presence of background noise, or to improve the signal-to-noise ratio (SNR). Interestingly, a specific group, namely musicians, received much attention in the audiological world. Researchers claim that musicians may have an advantage, or specifically a 'musician advantage', with regard to auditory perceptual abilities. These include better perception of speech in the presence of background noise (Parbery-Clark et al., 2013), or improved central auditory skills that may assist in better speech recognition in noise (Yeend et al., 2017), such as enhanced temporal resolution (Sangamanatha et al., 2012; Donai & Jennings, 2016), frequency discrimination (Boebinger et al., 2015; Madsen et al., 2019), pitch perception (Anand et al., 2017), sensitivity to sound (Varnet et al., 2015), or better cognitive abilities (Boebinger et al., 2015). Researchers also mentioned the positive effect of music on the plasticity of the brain (Patel, 2014).

In the study conducted by Sangamanatha et al. (2012), the temporal resolution abilities of 15 children (aged between 10-15 years) with musical expertise were studied by using a gap detection test. The researchers found that the children with musical backgrounds performed better than the children without musical exposure, and equally to non-musician adults aged between 20 and 30 years (Sangamanatha et al., 2012). Similarly, Anand et al. (2017) have found better performances in temporal processing tasks, including the pitch perception test and random gap detection test, in 20 school-aged children (10-16 years) who had received over two years of musical training

© University of Pretoria

compared to a non-musician group. These findings evident in younger individuals with musical training and musicians of advanced age (Grassi et al., 2017). Furthermore, improved auditory and cognitive skills, including frequency and duration discrimination tasks and complex working memory tasks, have been observed in 20 elderly musicians (aged between 65 and 84 years) with more than 46 years of musical training compared to non-musicians within the same age range (Grassi et al., 2017). It seems that musicians present with an advantage in auditory performance, whether the musicians have a hearing loss or not.

Parbery-Clark et al. (2013) conducted a study to determine if the musician advantage could also be observed in 17 middle-aged musicians (aged between 45-65 years) with mild-to-moderate hearing loss compared to individuals with little to no musical training also with mild-to-moderate hearing loss. The musicians received musical training since the age of nine years and were practising at least three times a week at the time of the study. The participants were assessed with speech in noise tests (the Hearing in Noise Test (HINT), a self-reported Speech, Spatial, and Qualities Questionnaire, and a test for working memory), and speech-evoked (/da/ at different frequencies) auditory brainstem responses (ABRs) in both quiet and noisy backgrounds. Results of the study indicated that musicians present with a significantly better ability to hear speech in noise and had stronger subcortical encoding of sound, better neural timing abilities, and improved neural encoding of speech frequencies, but not of higher pitched sounds. The musical advantage was still evident even though the musicians presented with hearing loss, and Parbery-Clark et al. (2013) recommended that musical training be included in rehabilitating individuals with hearing loss. Varnet et al. (2015) also suggested that musicians may perceive sound better, and musical training may enhance an individual's ability to listen to speech in noise. If musical training improves the ability to recognise speech in noise, the inclusion of musical training in the rehabilitation of patients with hearing loss or language-related disorders may be valuable (Parbery-Clark et al., 2013; Anand et al., 2017; Zhang et al., 2019).

However, in contrast to the abovementioned studies, other studies have found no significant differences in auditory and/or cognitive skills between a selected group of musicians and non-musicians, regardless of hearing abilities. In these studies, other factors such as cognitive abilities, psychoacoustic tasks, or better working memory

© University of Pretoria

capacity between individuals may be other reasons for improved speech in noise recognition (Yeend et al., 2017; Madsen et al., 2019; Bidelman & Yoo, 2020; Escobar et al., 2020). Yeend et al. (2017) conducted a larger study involving a total of 122 individuals exposed to noise and music, individuals without musical experience, and individuals with hearing-related problems. This study aimed to determine the effects of noise on auditory processing, as well as the effects of musical training on auditory temporal processing, even with the known negative effects of noise exposure. Although musical experience has been associated with improved auditory processing skills and enhanced neural responses to sound, their study indicated that the group who received musical training did not perform better on the speech in noise tests than the non-musical cohort. The researchers therefore suggested that other factors may also play a role in complex speech recognition tasks and not necessarily the sole advantage of musical training.

In the study conducted by Monteiro et al. (2010), a musician advantage in a young group of musicians compared to non-musicians could not be seen when temporal resolution skills were measured by a GIN test. The authors noted that the musician group performed slightly better, but not significant. A more recent study conducted by Escobar et al. (2020) found no difference in speech in noise performance and working memory skills between a musician group and non-musician group. The study also concluded that musical training does not necessarily account for the advantage to perform better in complex listening situations, and perhaps better speech in noise performances are only due to better working memory capacity of the individuals (Escobar et al., 2020). A study that assessed a group of 16 students with at least ten years of musical training found no difference in measures, including the HINT and QuickSIN, of voiced and whispered speech understanding in speech-spectrum noise compared to a non-musician group (Ruggles et al., 2014). Musicians' speech recognition in four different masking situations, including clear speech, spectrally rotated speech, speech-amplitude modulated noise, and speech-spectrum steady-state noise, between musicians and non-musicians, were determined (Boebinger et al., 2015). Interestingly, results indicated no difference in the performance of the participants on the speech in noise test across all masked conditions. The researchers suggested that general cognitive abilities should be considered rather than musical

© University of Pretoria

training if studies want to investigate musicians' performance on speech in noise test results.

In a study by Madsen et al. (2019), a musician group was compared to a non-musician group matched for age, gender, and intelligence. In the listening situations used in the study, the speech target and noise were either spatially separated or joined. The researchers could not find any difference in speech recognition in noise tasks across all listening conditions between the two groups. However, the researchers found significant improvement in the musician group's performances in the additional psychoacoustic tasks, including fundamental frequency discrimination, interaural time difference thresholds, and attentive tracking performance. Zhang et al. (2019) found in their study of 17 musicians compared to 17 non-musicians that the musician group had slightly poorer EHF thresholds, but no significant difference between the two groups. Likewise, no difference was found in speech in noise performance (Zhang et al., 2019). The researchers, however, found that the musician group performed better in the phasic listening condition (S_oN_o) but not the antiphasic condition ($S\pi N_o$) compared to the non-musicians. This supports the finding that the musician advantage may only be evident in complex listening situations (Yeend et al., 2017).

Nevertheless, speech understanding in noise is essential for everyday communication, and understanding the abilities involved in speech understanding in noise may provide better or increased insight into the entire auditory system (Hennessy et al., 2022). Lerousseau et al. (2020) suggest that music performance may require even higher levels of similar sensory and cognitive processing than what is required for speech recognition. According to Slater and Kraus (2016), a sensitivity for rhythm and timing, which is essential for musical performances, may enhance an individual's ability to perceive brief changes in acoustic stimuli, which may account for better temporal resolution abilities.

Temporal resolution is one of the four subprocesses, including temporal resolution, temporal integration, temporal sequencing and temporal masking (Braga et al., 2015; Musiek, 2016; Ronen et al., 2018) of temporal processing, which forms part of the central auditory pathways. These pathways are essential for the perception of verbal and non-verbal stimuli (Braga et al., 2015). Temporal processing can be defined as the perception of time influences on acoustic signals, and this can range from simple

© University of Pretoria

(neural timing) to more complex (cortical processing of binaural hearing and speech recognition) auditory tasks (Monteiro et al., 2010). Temporal resolution represents a person's ability to discriminate between brief changes in sounds, or in other words, the shortest time necessary to distinguish between two sounds (Braga et al., 2015; Musiek, 2016). Good temporal resolution ability is an essential part of speech understanding and music perception, as it enables an individual to decode complex acoustic signals in the presence of competing background noise (Iliadou et al., 2014; Braga et al., 2015). This ability may assist with better speech recognition in noise in individuals with normal hearing, those with hearing loss and hearing aids or cochlear implants, as well as those with central auditory processing disorders and in need of aural rehabilitation (Kumar et al., 2016). This ability can be assessed by psychoacoustic tests, including gap detection, duration discrimination, temporal order judgement (Musiek, 2016; Ronen et al., 2018), and speech recognition tests (Kumar & Sangamanatha, 2011).

As there are contradicting research and unclear conclusions about whether musicians have better speech recognition in noise abilities compared to non-musicians, the aim of the current study was to compare the temporal resolution and speech recognition in noise abilities between a group of musician participants and a group of non-musician participants with normal hearing sensitivity (PTA of ≤15dB). To achieve this aim, the participants were tested with conventional and extended high frequency (EHF) audiometry (0.25 to 16 kHz), the digits-in-noise (DIN) speech in noise test with two different listening conditions, including homophasic and antiphasic listening conditions, to measure the binaural intelligibility-level difference (BILD), and gaps-in-noise (GIN) test for temporal resolution.

© University of Pretoria

Chapter 2: Methodology

1. Research aim

The aim was to compare the speech recognition in noise and temporal resolution abilities of formally trained musicians to non-musicians with both groups having normal audiometric results (PTA ≤ 15 dB HL).

2. Research design

A cross-sectional between-group research design was used in this study (Edmonds & Kennedy, 2016; Brink et al., 2018). Participants were assigned to either the control group (non-musicians) or the research group (musicians) (Brink et al., 2018). With this research design, specific variables, namely the speech recognition in noise and temporal resolution abilities, were described and the differences between the two study groups were also described (Edmonds & Kennedy, 2016; Brink et al., 2018). The two groups were age- and gender-matched. The data from each participant was collected at a specific point in time (Brink et al., 2018).

A quantitative research approach was used for this study. Quantitative research aims to interpret the results systematically and objectively to answer the research question (Brink et al., 2018). This research approach involves formalized tests and procedures to ensure accurate and detailed interpretation of data (Edmonds & Kennedy, 2016; Brink et al., 2018). The DIN (De Sousa et al., 2020) and GIN (Musiek, 2016) provide numerical numbers for the participants' scores, allowing the speech recognition in noise and temporal resolution abilities to be quantified (Edmonds & Kennedy, 2016).

3. Ethical considerations

Ethical aspects should be considered for all research purposes, particularly when humans are the focus of the research conducted. Ethical approval for this study was granted by the Departmental Research and Ethics Committee of the Department of Speech-Language Pathology and Audiology, the Research Ethics Committee of the Faculty of Humanities (Appendix A), as well as the Survey Committee of the University of Pretoria (Appendix B). The following aspects were considered:

© University of Pretoria

2.3.1 Informed consent

Permission to recruit formally trained musicians was obtained from the Head of the Music Department at the University of Pretoria (Appendix C), as well as a lecturer of the Music Department at the University of Pretoria. Prior to participant selection and data collection, each participant was provided with an information leaflet and informed consent letter (Appendix D). Written consent was obtained from every participant.

2.3.2 Confidentiality

It is the researcher's responsibility to protect the privacy of participants, especially when humans are the focus of the research (Brink et al., 2018). This means that the researcher should take steps to protect participants' privacy and personal information from unapproved access, use, modification, disclosure, loss, and theft. In line with the POPIA (Accessible Law, 2020), the personal information obtained from the participant was not used to identify the participant during data analysis and had only been used for research purposes. An alphanumeric code (e.g. M1 or NM1) was assigned to each participant during data collection so that their results were reported confidentially. The participant's personal identity and case history information was only known to the researcher at the time of data collection.

2.3.3 Protection from harm

Researchers should recognise participants' right to be protected from discomfort and harm, whether physical, emotional, psychological, economic, social, or legal (Brink et al., 2018). There were minimal risks involved due to COVID-19, however all COVID-19 protocols had been followed. None of the study selection and data collection procedures performed could cause harm. This information was clarified in the informed consent letter (Appendix D) given to participants. Participants were treated and assessed respectfully and were given clear instructions about procedures and what was expected from them.

2.3.4 Anticipated benefits

Participants did not benefit directly from this research study. However, the results of this study may assist in the development of rehabilitation programmes for individuals

© University of Pretoria

with hearing and language related disorders. Participants received a free hearing test. Participants who presented with any auditory difficulties or hearing loss, he/she was referred (Appendix E) to the Department of Speech-Language Pathology and Audiology at the University of Pretoria where further testing and early intervention and management could take place.

2.3.5 Plagiarism

This research study adhered to the University of Pretoria's plagiarism policy and was the researcher's original work. All secondary material used in this study had been cited and referenced according to the APA 7th Edition referencing guidelines. A plagiarism declaration was signed by the researcher (Appendix F).

4. Sampling method

This research study selected the musician participants (research group) by using a purposive sampling method. Purposive sampling, also called judgemental sampling, is a non-probability sampling method where the researcher will select participants based on judgement of how well participants represent a typical candidate for the research study (Brink et al., 2018). The musician group participants, which consisted of young university adults, were invited by the lecturer of the Music Department (Appendix G) during a class at the University of Pretoria to participate in the research study. The musician students that were interested to participate in the study, contacted the principal researcher for further arrangements. To select participants for the non-musician group, purposive sampling was combined with convenience sampling to age and gender match the musician group and consisted of students from the Faculty of Humanities at the University of Pretoria, and friends of the researcher.

5. Participants

2.5.1 Selection criteria

The study included a total of 80 participants divided into two groups namely a research group that consisted of 40 participants (19 female, 21 male) who had received formal musical training (formally trained musicians) and a control group that consisted of 40 participants with no more than three years of musical experience over their lifetime

© University of Pretoria

(Boebinger et al., 2015; Bidelman & Yoo, 2020). The musician group consisted of young adults, aged between 18 and 30 years (mean 22.5 years), recruited from the Music Department at the University of Pretoria (Appendix G) by purposive sampling. Participants in the musician group were required to have formal musical training at a tertiary institution and instrumental musical experience of at least ten years, practising consistently at least three times a week over the last three years prior to this study (Parbery-Clark et al., 2013; Boebinger et al., 2015). Participants were also required to have normal hearing thresholds.

Normal hearing or near normal hearing was defined as behavioural pure tone hearing thresholds ≤15 decibel Hearing Level (dB HL) from 0.25 - 8 kHz (ASHA, 2020). Normal hearing was required as musicians may present with a music-induced hearing loss (MIHL). For participants to be included in the study, he/she also needed to be able to read and understand English to understand the case history questionnaire and assessment instructions.

Participants were excluded from the study if they had any of the following (i) a middle ear pathology in one/both ears at the time of assessment; (ii) a conductive hearing loss with an air-bone gap of >10 dB averaged 0.5 - 4 kHz in one/both ears; (iii) an external ear pathology in one/both ears; (iv) any tympanogram that is not type A in one/both ears; (v) previous otologic surgery; (vi) a history of exposure to ototoxic drugs; (vii) any type and degree of hearing loss (PTA 0.5 - 4 kHz > 15 dBHL); (viii) any family history of hearing-related diseases; (ix) any chronic medical or neurological conditions i.e. diabetes, high blood pressure, cholesterol, tuberculosis, HIV or Parkinson's; and (x) a history of traumatic brain injury (Kumar et al., 2012; Parbery-Clark et al., 2013; Boebinger et al., 2015; Slater & Kraus, 2016; Bidelman & Yoo, 2020). This criterion excluded all possible hearing and ear-related pathologies that could interfere with the hearing test results.

2.5.2 Material and apparatus for participant selection

The equipment outlined in Table 1 was used for participant selection.

Table 1 ***Equipment for participant selection***

Equipment	Motivation
Questionnaire (Appendix H)	Participants typed in their answers to the list of questions on the questionnaire that was developed with Qualtrics software.

© University of Pretoria

	Answers were evaluated to determine if participant was a candidate based on the selection criteria for the study. The personal and background history of the participants in the control group were used to age and gender match the control group with the research group.
Welch Allyn Pocketscope with reusable specula	This device was used for direct observation of the tympanic membrane and external auditory canal and offered valuable information about possible disease within the outer ear (Stach, 2010).
Inter-acoustics Titan IMP440	Acoustic immittance testing was conducted to objectively test the functioning of the tympanic membrane, the middle ear by a probe that was inserted in the participants' external auditory canal. The measurement was made automatically, and results obtained were used to identify middle ear pathologies.
hearTest™ smartphone	Each ear was tested separately at 0.25, 0.5, 1, 2, 4, 8 kHz to determine the participants' air conduction thresholds. The hearTest™ is a certified pure tone audiometer (IEC 60645-1) on a smartphone (SMA320F) and was used with calibrated Sennheiser HDA 300 circumaural headphones (Bornman et al., 2019).

2.5.3. Participant selection procedure

Each participant received an information leaflet and informed consent letter (Appendix D) regarding the details of the study before any testing commenced. Once the participant provided his/her consent to participate, the participant completed a short case history questionnaire developed by Qualtrics software. Answers from the questionnaire were used by the principal researcher to determine if the participant was a possible candidate for the study according to the selection criteria. Following the questionnaire each participant who was a possible candidate for the study, were invited to attend a one hour auditory evaluation at the Department of Speech-Language Pathology and Audiology at the University of Pretoria.

Participant selection procedures were conducted at the Department of Speech-Language Pathology and Audiology in the following order: otoscopic examination, immittance testing, and pure tone audiometry. If the participant adhered to the selection criteria and gave consent to participate, the research procedures, including the data collection procedures, commenced. Participants who presented with any auditory difficulties or hearing loss at any point in the testing procedures, were referred to the Department of Speech-Language Pathology and Audiology at the University of Pretoria where further testing and management could take place (Appendix E).

© University of Pretoria

2.5.3.1 Informed consent

An informed consent letter (Appendix D) written in English was given to each participant. This letter consisted of the information letter and the consent form. The information sheet explained the following: the purpose of this research, procedures and expectations from participants, duration, risks, benefits, rights, confidentiality, and data storage (WHO, 2020). The informed consent form also, in line with the Protection of Personal Information Act (2020), clearly stated the necessary contact information of the researchers. Participants were assured that participation was voluntary and that they were allowed to withdraw at any moment without any negative consequences (POPIA (Assessable Law, 2020)). The informed consent letter also explained COVID-19 safety procedures that were to be followed. There was an opportunity for each participant to ask for any clarification of any aspect of the research study and test procedures. A consent letter was given to each participant. All participants that were selected was 18 years and older and could give consent to participate in the study. Once consent was provided, test procedures in a quiet room commenced.

2.5.3.2 Case history questionnaire

A case history questionnaire (Appendix H), written in English and developed by Qualtrics software, was provided to the participant after consent had been given. The questionnaire contained questions related to family history, medical history, otological history and musical experience. Participants were given an opportunity to ask for any clarification on the questionnaire questions if there was any confusion. Provided answers were then evaluated by the researcher to determine if the participant was a candidate for this study. All participants' information as well as questionnaire answers remained confidential. This information was only used for the purpose of this research study.

2.5.3.3 Otoscopic examination

The researcher conducted an otoscopic examination with a Welch Allyn Pocketscope and reusable specula to inspect the external ear canal, tympanic membrane condition or detect abnormalities, such as external otitis media, foreign bodies, or occluding

© University of Pretoria

cerumen conditions. Results were recorded by the researcher on the data collection sheet (Appendix I) and the Microsoft Excel data collection spreadsheet.

2.5.3.4 Acoustic immittance testing

Immittance testing and the results were used to exclude middle ear pathologies, such as otitis media. Tympanometry was conducted with a 226 Hz probe (Interacoustics, 2017) and tested the function of the tympanic membrane and the status of the middle ear. Participants were required to have normal (Type A) tympanograms with a compliance of 0.3 – 1.75 ml, an ear canal volume of 0.2 – 2 ml and a middle ear pressure of -50 - +50 daPa to be included in the study. Jerger's (1970) tympanogram classification table was used as a guide to determine if the individual's tympanometry results were typical or atypical. Test results were recorded by the researcher on the data collection sheet (Appendix I) and the Microsoft Excel data collection spreadsheet.

2.5.3.5 Pure tone audiometry

Pure tone audiometry was conducted in a quiet room using a hearTest™ with Sennheiser HDA 300 circumaural headphones (Bornman et al., 2019) A self-administered automated test protocol of the hearTest™ smartphone (SMA320F) was used to test participants' air conduction hearing thresholds of each ear separately at 0.25, 0.5, 1, 2, 4, and 8 kHz. Results were recorded by the researcher on the data collection sheet (Appendix I) and the Microsoft Excel data collection spreadsheet.

2.5.4 Participant description

There were 40 participants in each group. Participants in the musician (research) group and non-musician (control) group were similar for age and gender. The musician group's mean age was 23.20 years and the non-musician group's mean age was 22.03 years. Both groups consisted of 21 males and 19 females. The musician group participants all had formal musical training at the University of Pretoria. Non-musicians who received musical training over the course of their life, reported in the Qualtrics questionnaire musical training more than five years ago.

© University of Pretoria

2.6 Data collection

2.6.1 Material and apparatus for data collection

The equipment outlined in Table 2 was used for data collection.

Table 2 ***Equipment for data collection***

Equipment	Motivation
hearTest™ smartphone	Extended high frequency air conduction thresholds at 10, 12.5, and 16 kHz of each ear were tested. The hearTest™ is a certified pure tone audiometer (IEC 60645-1) on a smartphone (SMA320F) and was used with calibrated Sennheiser HDA 300 circumaural headphones (Bornman et al., 2019).
hearTest™ smartphone Digits-in-noise	The South African English DIN was downloadable on iOS and Android smartphones (De Sousa et al., 2020). For this study, the DIN test was performed on a Samsung (SMA320F) in a quiet room with supra-aural headphones (Bornman et al., 2019). Both antiphasic and phasic listening conditions were tested in random order.
Gaps-in-noise CD	The GIN test is a monaural test recorded on a CD and consisted of four lists, each one with the total of 60 items (Wong & McPherson, 2015). The test was coupled with a two-channel Grason-Stadler GSI 61 audiometer and conducted on a sound-proof booth (Musiek, 2016).

2.6.2 Procedures for data collection

Once the participants were screened for eligibility and informed consent obtained, the testing procedures were commended. All the testing procedures were conducted on one day at a given time that was convenient for the participant. The data collection procedures were conducted at the Department of Speech-Language Pathology and Audiology at the University of Pretoria. The following procedures for data collection were conducted in this order:

2.6.2.1 Extended high frequency (EHF) audiometry

This test was conducted in a sound-proof booth to minimize the background noise. EHF audiometry may be more sensitive to hearing threshold shifts due to noise exposure than the standard pure tone audiometry, which tests frequencies 0.25-8 kHz (Interacoustics, 2016; Lindenbaum, 2017). Research indicated that the inclusion of EHF audiometry may reveal an earlier decrease in hearing or auditory function due to factors such as high levels of noise exposure and having an essential role in speech perception and should be used with conventional audiometry (Hunter et al., 2020).

© University of Pretoria

Participants were instructed to raise their hand when a tone was heard. The obtained results were recorded on the smartphone and written down by the principal researcher on a data collection sheet (Appendix I) and the Microsoft Excel data collection spreadsheet.

2.6.2.2 South African English Digits-in-noise (DIN) test

Homophasic (or diotic) DIN presented identically phased digits and noise to both ears simultaneously. Homogenized diotic, phased digits were used for the homophasic listening condition, and the same digit triplet occurred more than once (Potgieter, et al., 2015; De Sousa et al., 2020). There were 500 msec silent intervals before and after each digit-triplet, with successive digits being separated by 200 msec of silence and 100 msec of jitter. The test used a fixed noise level, variable speech level and a negative SNR. To prevent signal clipping, the speech level was fixed, and variable noise levels were used once the SNR became positive. Speech weighted masking noise of 70 dB SPL was presented inter-aurally in-phase. The SNR started at 0 dB SNR. For every correct response, SNR became 4 dB higher SNR the first three times, then 2 dB after these three times. For every incorrect response, SNR became 2 dB lower SNR. Correct responses were taken when all three digits were correct. There were 23 digit triplet presentations, of which the last 19 presentations were used to calculate the SRT (De Sousa, et al., 2020).

The antiphasic DIN presented 180-degree phase reversed digits in diotic noise. Each digit-triplet presentation had a 500 ms silent interval before and after and were separated by 200 ms of silence and 100 ms of jitter. The test used a fixed noise level, variable speech level, and a negative SNR. The speech level was fixed to prevent signal clipping, and the variable noise levels were used once the SNR became positive. A speech weighted masking noise of 70 dB SPL was presented inter-aurally in-phase. The SNR started at 0 dB SPL; with every correct response, the SNR increased by 4 dB the first three times and 2 dB after the first three times. For every incorrect response, the SNR decreased by 2 dB. Correct responses were taken when all three digits were correct. The test consisted of a total of 23 digit triplet presentations, randomly selected from a list of 120 digit triplets, of which the last 19 presentations were used to calculate the SRT (De Sousa et al., 2020).

© University of Pretoria

Details were inserted on the smartphone (SMA320F) before the testing, as required by the app: there were 5 screens. The first screen was a tutorial with instructions. The participant's age, gender, and alphanumeric code assigned to him/her were then inserted. Participants were instructed to adjust the loudness volume of the presentations to a comfortable level, start the test, and listen to the 23 digit triplet presentations in noise (Potgieter et al., 2015). Each participant completed the test by entering the triplets heard on the smartphone screen. The results obtained were displayed on the smartphone screen and recorded by the principal researcher on the data collection sheet (Appendix I) and Microsoft Excel data collection spreadsheet.

The BILD examines the difference in the 50% intelligibility levels between two binaural listening conditions (Ho et al., 2015) or, in other words, measure the ability to spatially set apart speech stimuli from noise stimuli and understand speech in the presence of background noise. BILD performances may be used to determine central auditory functions (Musiek & Chermak, 2015; Zhang et al., 2019) and a predictor to speech recognition in noise performances. Should there be an abnormal BILD, there may be possible asymmetrical hearing problems (Neher, 2017). The SNR thresholds for the homophasic (S_oN_o) and antiphasic ($S\pi N_o$) listening conditions used to calculate BILD were determined using the DIN test. The dB SNR value for BILD was then calculated (S_oN_o - $S\pi N_o$) (Zhang et al., 2019; Wolmarans et al., 2021), and recorded on the Microsoft Excel data collection spreadsheet.

2.6.2.3 Gaps-in-noise (GIN) test

The GIN test was developed to determine temporal resolution abilities in individuals (Musiek, 2016). The GIN test (a monaural test recorded on a CD) consists of 6s broadband uniform white noise stimuli with a 5s interstimulus interval. Each stimulus had at least zero to three silent intervals ranging from 2-20 ms (2, 3, 4, 5, 6, 8, 10, 12, 15, and 20) randomized and varied gap durations (Musiek, 2016; Iliadou et al., 2017). Each gap duration occurred six times during a standard list with 60 items (Musiek, 2016). The test consisted of four lists, each one with the total of 60 items (Wong & McPherson, 2015). The test was conducted monaurally, beginning with a practice list to ensure that participants understood the test. The four lists were randomized, but each participant was required to complete two lists per ear. The four lists with the best obtained results were used for the data analysis of this study. Each list was presented

© University of Pretoria

at an intensity level of 50 dB above the obtained PTA (Musiek, 2016). Two measures were taken, including a percentage of correct items on the 60-item list and an approximate threshold (A.Th) that was calculated based on the shortest gap duration detection on at least four out of six (4/6) gaps and better performance, for e.g., 6/6 gaps (Iliadou et al., 2017). A normal hearing ear typically obtain a score of 4.5 - 4.97 ms (Musiek, 2016).

The GIN test was conducted in a quiet and calibrated booth at the Department of Speech-Language Pathology and Audiology. Before the test commenced, practise items were given to the participants to ensure that the test is well understood. Participants were instructed to indicate by raising their hand when a gap was heard, and the results were recorded on the standard GIN score sheets, specifically designed for each track list (Wong & McPherson, 2015; Musiek, 2016). Results were recorded by the principal researcher on the data collection sheet (Appendix I) and Microsoft Excel data collection spreadsheet. The scoring sheet (Appendix I) contained the location and duration of gaps, and total percentage of corrected items on the item list.

2.7 Data processing and analysis procedures

The results of this study included hearing thresholds in dB HL from pure tone audiometry and EHF audiometry, SNR scores from two conditions, as well as the BILD, of the DIN test, and percentage and A.th. scores of the GIN test. A comparative analysis between the musician group and non-musician group across all test results was done. For the data analysis of this study, pure tone thresholds higher than 40 dB HL were recorded as 45 dB HL, instead of a no response (NR). The use of NR was not suited for data analysis and therefore it was recorded as numerical value. The results of the two lists with the best obtained results, i.e., list number one and number four were used for this study. Both descriptive and inferential statistics were used in this study. To summarise and simplify the data obtained, descriptive statistics were used by measures of central tendency specific to the research sample (Brink et al., 2018). Inferential statistics were used to analyse the significant or insignificant differences between the two groups being compared (Brink et al., 2018). Data were captured on Microsoft Excel spreadsheets before analysed using IBM SPSS Statistics 28. The means and standard deviations for all participants and all test results were obtained, and 95% confidence interval for the mean was used. Shapiro-Wilk test was

© University of Pretoria

used to check for normality of continuous variables (Field, 2018). The non-parametric test, namely the Mann-Whitney U test, analysed the abnormally distributed data (Field, 2018). To determine statistically significant differences between the musician and non-musician groups across all tests, a Mann-Whitney *U* test were used. The results were considered significant if $p < 0.05$ (Field, 2018).

2.8 Reliability and validity

It is essential to consider validity and reliability of data collection instruments when conducting research (Heale & Twycross, 2015).

Validity refers to the extent to which the study accurately measures the intended concept (Heale & Twycross, 2015). Another measure of research quality is reliability, which is the measure of the accuracy of the instrument, in other words the degree of the instrument's consistency when used repeatedly by researchers (Heale & Twycross, 2015; Brink et al., 2018). Validity and reliability were obtained in this study by the following measures:

- Each participant was selected according to the same inclusion and exclusion criteria.
- All participants received the same comprehensive instructions for each procedure and had the opportunity to clarify any uncertainties before testing procedures commenced.
- Each participant underwent the same selection and data collection procedures in the same order and in the same environmental conditions.
- Data collection instruments were calibrated according to SANS 10154-1 protocol.
- The DIN test was in English for all participants as language does not affect test results (Low et al., 2018).
- The DIN test was independent on the type of headphone used (Potgieter et al., 2015).
- The DIN test had been proven to be accurate and correlate well with sensitivity and specificity to pure tone audiometry and EHF (Potgieter et al., 2015; Bornman et al., 2019).

© University of Pretoria

- The GIN test had been proven clinically accurate and reliable to give more information on the central nervous system (Iliadou et al., 2014).

© University of Pretoria

Chapter 3: Research article

This article was submitted to the Journal of Speech, Language and Hearing Research (JSLHR). The article was prepared and written according to the journal's specification and therefore the formatting differs from that of the dissertation.

Speech recognition in noise and temporal resolution: A comparison between formally trained musicians and non-musicians

Authors: Michèle Schoeman[a], Lidia Pottas[a], Maggi Soer[a], Karina C. De Sousa[a] and Marien Graham[b].

[a] University of Pretoria, Department Speech-Language Pathology and Audiology

[b] University of Pretoria, Department of Science, Mathematics and Technology Education

Journal: Journal of Speech Language and Hearing Research (JSLHR)

Submitted (see Appendix H): 27 October 2022

3.1. Abstract

Purpose: This study compared the speech recognition in noise and temporal resolution abilities in formally trained musicians with normal hearing to a similar group of non-musicians.

Method: A quantitative cross-sectional comparative group research design was used in this study. Each participant's conventional and extended high frequency (EHF) pure tone thresholds, homophasic and antiphasic speech recognition in noise thresholds (SRT), and temporal resolution were tested. A binaural intelligibility-level difference was calculated using the values obtained in the homophasic and antiphasic listening conditions. Forty formally trained musicians and 40 age and gender-matched non-musicians participated. Selection procedures included otoscopy, tympanometry, and pure tone audiometry. All participants presented with PTA thresholds at 0.5 to 4 kHz < 15 dB HL.

© University of Pretoria

Results: No significant group differences were obtained in EHF, DIN and BILD, or the GIN test. Although the musicians achieved slightly better results in the speech recognition in noise and temporal resolution tests, the differences were not significant ($p > .05$).

Conclusions: Musicians performed slightly better, although not significantly different than non-musicians in the GIN testing and the DIN test. No statistically significant difference between the two groups in BILD was observed.

Keywords: musicians; temporal resolution; speech recognition in noise; extended high frequencies

3.2. Introduction

Temporal resolution, a subprocess of temporal auditory processing, represents a person's ability to discriminate between brief changes in sounds, or in other words, the shortest time necessary to distinguish between two sounds (Braga et al., 2015; Musiek, 2016). This ability can be assessed by psychoacoustic tests, including gap detection, duration discrimination, temporal order judgement (Musiek, 2016; Ronen et al., 2018), and speech recognition tests (Kumar & Sangamanatha, 2011). Temporal resolution is essential to speech understanding and music perception, as it enables an individual to decode complex acoustic signals in the presence of competing background noise (Iliadou et al., 2014; Braga et al., 2015). A hearing loss or decline in auditory processing abilities may contribute to difficulties in understanding speech, especially in noise, and result in communication barriers, limiting an individual and bringing forth feelings of loneliness and isolation (Parbery-Clark et al., 2013). Continuous research is needed to find new ways to improve speech-in-noise abilities and improve quality of life.

A specific group, namely musicians who received lifelong musical training, has recently been a topic of interest. According to Slater and Kraus (2016), sensitivity to rhythm and timing, an essential part of musical performances, may even enhance an individual's ability to discriminate between brief sound changes. Lerousseau et al. (2020) suggest that music performance may require higher levels of similar sensory and cognitive processing than what is required for speech recognition. It is speculated that musical training may improve the ability of individuals with hearing loss to

© University of Pretoria

understand speech in noise, and to enhance their social and emotional confidence (Parbery-Clark et al., 2013).

As musicians may have better perceptual abilities, including speech-in-noise perception (Anaya et al., 2016), researchers often refer to a 'musician advantage' to describe musicians with enhanced auditory performance (Parbery-Clark et al., 2013). However, findings have been contradicting several studies displaying differences in auditory performances between musicians and non-musicians (e.g., Sangamanatha et al., 2012; Parbery-Clark et al., 2013; Varnet et al., 2015; Anand et al., 2017; Grassi et al., 2017), and others displaying no significant differences (e.g., Ruggles et al., 2014; Yeend et al., 2017; Madsen et al., 2019; Bidelman & Yoo, 2020; Escobar et al., 2020).

Sangamanatha et al. (2012) found that children with musical backgrounds performed better in the gap detection test than children without musical exposure and equally to non-musician adults. Anand et al. (2017) determined that a group of school-aged musicians performed better in temporal processing tasks, specifically pitch perception and random gap detection tests, compared to a non-musician participant group. These findings were evident in younger individuals with musical training and musicians of advanced age (Grassi et al., 2017). Parbery-Clark et al. (2013) used various speech-in-noise tests (the HINT, a self-reported Speech, Spatial, and Qualities Questionnaire, and a test for working memory) and speech-evoked (/da/ speech sound at different frequencies) ABR both in a quiet environment and in six different noisy backgrounds, to compare the performances of middle-aged musicians with mild-to-moderate hearing loss to non-musicians with the same hearing loss. The authors reported that musicians presented with a significantly better ability to hear speech in noise, had more robust subcortical encoding of sound, better neural timing abilities, and improved neural encoding of speech frequencies, but not in the higher pitched sounds. The musical advantage was still evident even though the musicians presented with hearing loss, and Parbery-Clark et al. (2013) recommended that musical training be included in rehabilitating individuals with hearing loss. Varnet et al. (2015) also suggested that musicians may perceive sound better, and musical training may enhance an individual's ability to listen to speech in noise.

© University of Pretoria

In contrast to the abovementioned studies, Yeend et al. (2017) reported no difference in performance in speech-in-noise tests between music and noise-exposed individuals, individuals without music training, and individuals with hearing-related problems. Similarly, a recent study conducted by Escobar et al. (2020) found no difference in speech-in-noise performance and working memory skills between a musician group and a non-musician group. Ruggles et al. (2014) found no difference in performances of tests, including the HINT and QuickSIN, of voiced and whispered speech understanding in speech-spectrum noise between musician students and non-musician participant groups. Insignificant differences in the performances of musicians compared to non-musicians were obtained in speech recognition ability in four different masking situations, including clear speech, spectrally rotated speech, speech-amplitude modulated noise, and speech-spectrum steady-state noise in the study of Boebinger et al. (2015).

Madsen et al. (2019) used spatially separated or joined speech-in-noise tests to compare the performances of a group of musicians, and age, gender, and an intelligence-matched non-musician participant group. The researchers wanted to assess if the musician advantage would be evident in a more natural listening situation than previously tested. No difference in speech recognition in noise tasks across all listening conditions between the two participant groups was obtained. However, a significant improvement was found in the musician group's performances in the additional psychoacoustic tasks, including fundamental frequency discrimination, interaural time difference thresholds, and attentive tracking performance. With regard to extended high-frequency thresholds and speech-in-noise performance using QuickSIN, Zhang et al. (2019) did not find any difference between musicians and non-musicians. The researchers, however, found that the musician group performed better in the phasic listening condition (S_0N_0) but not in the antiphasic condition ($S\pi N_0$) compared to the non-musicians, which supports the finding of Yeend et al. (2017) that the musician advantage may only be evident in complex listening situations.

Speech recognition in noise is essential for everyday communication, and understanding the abilities involved in speech recognition in noise may provide better or increased insight into the entire auditory system (Hennessy et al., 2022). If musical training improved the ability to recognize speech in noise, the inclusion of musical

© University of Pretoria

training in the rehabilitation of patients with hearing loss or language-related disorders might be valuable (Parbery-Clark et al., 2013; Anand et al., 2017; Zhang et al., 2019). As there are contradicting research and unclear conclusions about whether musicians have better speech recognition in noise abilities compared to non-musicians, the current study aimed to compare the temporal resolution and speech-in-noise abilities between a group of musician participants and a group of non-musician participants with normal hearing sensitivity.

3.3. Materials and method

3.3.1. Study design and Participants

A quantitative cross-sectional comparative groups research design was used. A total of eighty participants (40 musicians and 40 non-musicians) were selected using a convenience sampling approach (Brink et al., 2018). The two groups were age- and gender-matched and consisted of 19 females and 21 males, aged between 18 and 30 years (mean=22.62 years). Musicians had to have formal music training and experience in instrumental music of at least ten years and practised consistently at least three times a week over the last three years before participation in this study (Parbery-Clark et al., 2013; Boebinger et al., 2015). The non-musicians had no more than three years of musical experience over their lifetime (Boebinger et al., 2015; Bidelman & Yoo, 2020). All participants had normal otological outer and middle ear function, as confirmed through otoscopy and tympanometry. Normal middle ear functioning was indicated if the participant had a type A tympanogram result with a compliance value of 0.3 – 1.75 ml, an ear canal volume of 0.2 – 2 ml and a middle ear pressure of -50 - +50 daPa. Jerger's (1970) tympanogram classification table was used to determine if the individual's tympanometry results were typical or atypical. Furthermore, all participants had normal hearing across 0.25, 0.5, 1, 2, 4, and 8 kHz, as one of the inclusion criteria was that the pure tone threshold at all frequencies should be no more than 15 dB HL. Two musician participants were excluded from the study due to abnormal hearing sensitivity thresholds in the conventional frequency range. Ethical clearance for this study was obtained from the Research Ethics Committee of the Faculty of Humanities, and the Survey Committee of the University of Pretoria (protocol number: HUM055/0821).

© University of Pretoria

3.3.2. Procedures and Equipment

3.3.2.1. Pure tone audiometry

Air conduction thresholds were determined in a sound-proof booth at conventional frequencies (0.25, 5, 1, 2, 4, and 8 kHz) as well as EHF (10, 12.5 and 16 kHz) bilaterally using the hearTest™ (Samsung SM-A320F) coupled with Sennheiser HDA300 circumaural headphones (Bornman et al., 2019) The mean pure tone average (PTA) was calculated by using four frequencies, namely 0.5, 1, 2, and 4 kHz. An EHF PTA was calculated using 10, 12.5, and 16 kHz for each ear. Research indicated that the inclusion of EHF audiometry may reveal an earlier decrease in hearing or auditory function due to factors such as high levels of noise exposure and having an essential role in speech perception and should be used with conventional audiometry (Hunter et al., 2020).

3.3.2.2. Digits-in-noise test

Speech recognition in noise was tested by using a South African English digits-in-noise test (DIN), performed on a smartphone (Samsung SMA320F). Testing was done in a quiet room with supra-aural headphones (Bornman et al., 2019). Two listening conditions, namely antiphasic and homophasic, were tested randomly. Homophasic (or diotic) DIN presented identically phased digits and noise to both ears simultaneously, while the antiphasic DIN presented 180-degree phase reversed digits in diotic noise. Homogenized diotic, phased digits were used for the homophasic listening condition, and the same digit triplet occurred more than once (Potgieter et al., 2015; De Sousa et al., 2020). Each digit triplet presentation had a 500 ms silent interval before and after and was separated by 200 ms of silence and 100 ms of jitter. The test used a fixed noise level, a variable speech level, and a negative SNR. The speech level was fixed to prevent signal clipping, and the varying noise levels were used once the SNR became positive. A speech-weighted masking noise of 70 dB SPL was presented inter-aurally homophasic. The SNR started at 0 dB SPL; with every correct response, the SNR increased by 4 dB the first three times and 2 dB after the first three times. For every incorrect response, the SNR decreased by 2 dB. Correct responses were taken when all three digits were correct. The test consisted of 23 digit triplet presentations, randomly selected from a list of 120 digit triplets, of which the last 19

© University of Pretoria

presentations were used to calculate the SRT (De Sousa et al., 2020).

Participants were instructed to adjust the loudness volume of the presentations to a comfortable level, start the test, and listen to the 23-digit triplet presentations in noise. Each participant completed the test by entering the triplets heard on the smartphone screen.

The BILD examines the difference in the 50% intelligibility levels between two binaural listening conditions (Ho et al., 2015) or, in other words, measures the ability to spatially set apart speech stimuli from noise stimuli and understand speech in background noise. BILD performances may be used to determine central auditory functions (Musiek & Chermak, 2015; Zhang et al., 2019) and to predict speech recognition in noise performances. Should there be an abnormal BILD, there may be possible asymmetrical hearing problems (Neher, 2017). The SNR thresholds for the homophasic (S_oN_o) and antiphasic ($S\pi N_o$) listening conditions used to calculate BILD were determined using the DIN test. The dB SNR value for BILD was then calculated (S_oN_o - $S\pi N_o$) (Zhang et al., 2019; Wolmarans et al., 2021).

3.3.2.3. Gaps-in-noise test

Temporal resolution was tested using the GIN test, which consisted of 6s broadband uniform white noise stimuli with a 5s interstimulus interval (Iliadou et al., 2014). Each stimulus had at least zero to three randomized and varied gap durations ranging from 2-20ms (2, 3, 4, 5, 6, 8, 10, 12, 15, and 20) (Musiek, 2016; Iliadou et al., 2017). Each gap duration occurred six times during a standard list with 60 items (Musiek, 2016). The test consisted of four lists, each with 60 items (Wong & McPherson, 2015). The test was conducted monaurally, beginning with a practice list to ensure that participants understood the test. Participants were instructed to indicate when a gap was heard, and the results were recorded on the standard GIN score sheets, specifically designed for each track list (Wong & McPherson, 2015; Musiek, 2016). The lists were randomized, and the two best-obtained result lists were used for the data analysis of this study. Each list was presented at an intensity level of 50 dB above the obtained PTA (Musiek, 2016). An approximate threshold (A.th.) was taken and calculated based on the shortest gap duration detection on at least four of six (4/6) gaps or better performance (Donai & Jennings, 2016; Musiek, 2016). False positives

© University of Pretoria

were subtracted from the total and percentage of correct items on the 60-item presented list (Musiek, 2016).

3.4. Statistical Analysis

The results of this study included hearing thresholds in dB HL from pure tone audiometry and EHF audiometry, SNR scores from two conditions, as well as the BILD of the DIN test, and the percentage and A.th. scores of the GIN test. A comparative analysis between the musician group and non-musician group across all test results was done. For the data analysis of this study, pure tone thresholds higher than 40 dB HL were recorded as 45 dB HL instead of a no response (NR). The results of the two lists with the best-obtained results, i.e., list number one and number four, were used for this study.

IBM SPSS Statistics 28 were used to analyse all data. The means, standard deviations and results for all participants were obtained, and a 95% confidence interval for the mean was used. The Shapiro-Wilk test was used to check for the normality of continuous variables (Field, 2018). The parametric tests (*t*-test and one-way ANOVA test) analysed normally distributed data, and the non-parametric tests (Mann-Whitney *U* test and Kruskal-Wallis test) analysed abnormally distributed data (Field, 2018). The results were considered significant if $p < 0.05$ (Field, 2018). To determine statistically significant differences between the musician and non-musician groups across all tests, A Mann-Whitney *U* test was used.

3.5. Results

3.5.1. Pure tone audiometry

Figures 1 and 2 show the mean hearing thresholds from 0.25 to 16 kHz for the musician and non-musician groups. At all the frequencies tested, the mean hearing thresholds for both groups from 0.25 to 12.5 kHz in both ears were ≤ 15 dB HL. Both the musician and non-musician groups presented with thresholds of more than 15 dB HL at 16 kHz in both ears. The mean PTA in the musician group for the left and right ears were 5.50 dB HL (SD = 3.58) and 5 dB HL (SD = 3.25), respectively. The mean PTA in the non-musician group for the left and right ears were 4.88 dB HL (SD = 2.82) and 3.59 dB HL (SD = 2.70), respectively. The mean EHF PTA's were 10.75 dB HL

© University of Pretoria

(SD = 9.19) and 9.38 dB HL (SD = 7.93) for the left and right ear of the musician group, respectively, and 10.12 dB HL (SD = 10.17) and 9.83 dB HL (SD = 8.20) for the left and right ears of the non-musician group.

There were no significant differences in the PTA thresholds between the musician and non-musician groups in the left [U = 744, p = 0.59] or right [U = 600, p = 0.05] ears. Similarly, the mean EHF PTA thresholds were not statistically significantly different between the musician and non-musician groups in either left or right ears, U = 763, p = 0.72; U = 789, p = 0.92.

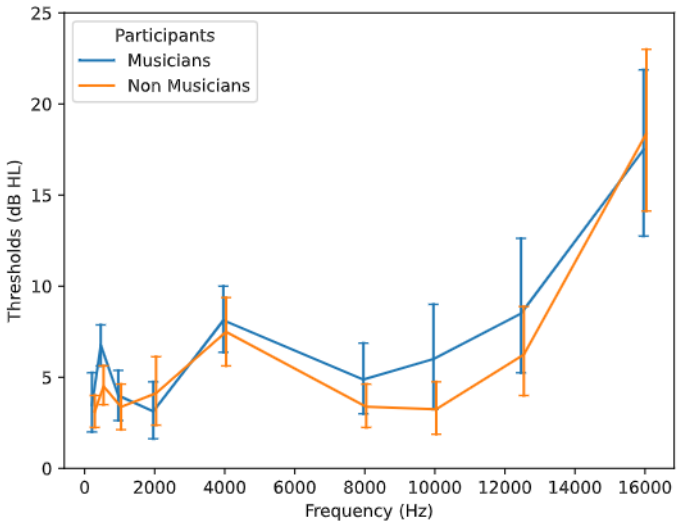
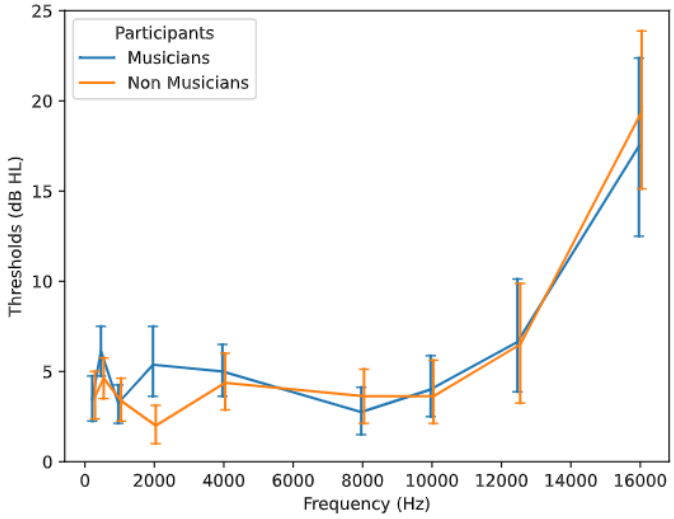


Figure 1 ***Mean and standard deviations of pure tone thresholds of the left ears between musicians and non-musicians.***



© University of Pretoria

Figure 2 ***Mean and standard deviations of pure tone thresholds of the right ears between musicians and non-musicians.***

3.5.2. Digits-in-noise test

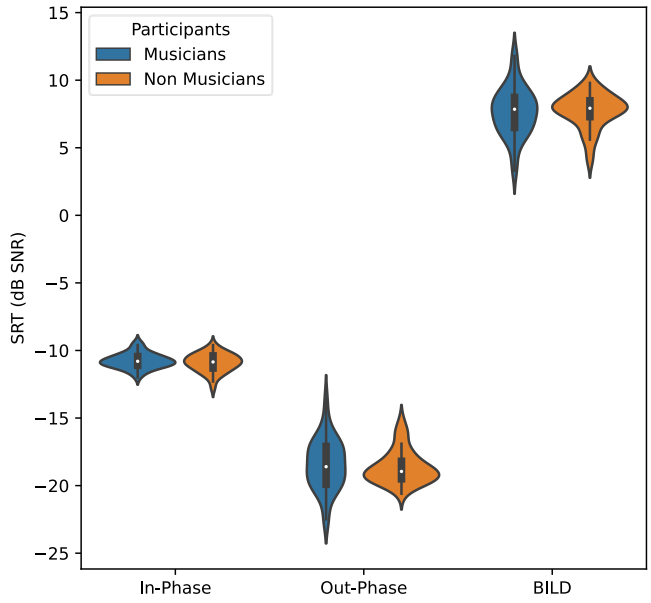


Figure 3 ***DIN SRT thresholds for the homphasic and antiphasic listening conditions, as well as the BILD for both musician and non-musician groups.***

The mean SRT scores in the musician and non-musician groups for the homphasic listening condition were -10.77 dB SNR (SD = 0.56) and –10.91 dB SNR (SD = 0.68), respectively. For the out-phase listening condition, the musician group obtained a mean SRT score of -18.44 dB SNR (SD = 1.86), and the non-musician obtained a mean SRT score of -18.64 dB SNR (SD = 1.23). The mean SRT scores were not significantly different between the musician and non-musician groups, U = 732, p = 0.51. In the antiphasic condition, the mean SRT scores were also not significantly different between the musician and non-musician groups, U = 742.5, p = 0.58.

The mean BILD (homophasic/S_oN_o minus antiphasic/$S\pi N_o$) SRT threshold in the musician group and the non-musician group were 7.67 dB SNR (SD = 1.79) and 7.73

© University of Pretoria

dB SNR (SD = 1.28), respectively and were not different between the two groups, *U* = 765.5, *p* = 0.74.

3.5.3. Gaps-in-noise test

An approximate threshold (A.th.) was taken and calculated based on the shortest gap duration detection on at least four of six (4/6) gaps or better performance (Donai & Jennings, 2016; Musiek, 2016). False positives were subtracted from the total and percentage of correct items on the 60-item presented list (Musiek, 2016). The means and standard deviations of the total percentages of correct items obtained by the musician and non-musician participants for each ear, as well as the A.th. per list, are shown in Table 1.

Table 3 ***GIN test means and SD of total percentage and A.th. between musicians and non-musicians.***

		Total percentage (%)		A.th. (ms)	
		Mean	**SD**	**Mean**	**SD**
Musicians	**Left**	70.30	7.06	5.74	1.46
	Right	70.68	8.35	5.22	1.35
Non-musicians	**Left**	74.12	3.59	4.88	0.72
	Right	73.07	5.10	5.26	1.09

P < 0.05*

The non-musician group performed better, but not significantly different from the musician group in the GIN total percentages in the left [*U* = 84.5, *p* = 0.06] or right [*U* = 311, *p* = 0.63]. There were no statistically significant differences between the two groups in the A.th. scores in either left or right ears [*U* = 83.5, *p* = 0.05; *U* = 309, *p* = 0.60].

3.6. Discussion

Evidence regarding the speech recognition of musicians in noise compared to non-musicians to date has been mixed, with some support for enhanced abilities (e.g. Sangamanatha et al., 2012; Parbery-Clark et al., 2013; Varnet et al., 2015; Donai & Jenings, 2016; Anand et al., 2017; Grassi et al., 2017) but other studies were finding non-significant differences (e.g. Ruggles et al., 2014; Yeend et al., 2017; Madsen et

© University of Pretoria

al., 2019; Zhang et al., 2019; Bidelman & Yoo, 2020; Escobar et al., 2020). The goal of this study was to compare the musician and non-musician groups in conventional audiometry and EHF audiometry (0.25 to 16 kHz), phasic and antiphasic DIN, BILD, and the GIN test. The results indicated no group difference across all the tests.

In this study, the non-musician group performed slightly, but not significantly better, in the GIN thresholds. Other literature reports the contrary, showing enhanced temporal resolution skills (Sangamanatha et al., 2012; Donai & Jennings, 2016). The findings of this study, however, correlate more with the results of Monteiro et al. (2010), who also found no significant differences in GIN test performances on either left or right ears between violinist musicians and their control group, who were non-musicians matched for age (mean age of 24.6 y) and education. A more significant effect between the two groups would perhaps be noted if another age group, either a younger or older participant group, were included in the study (Ruggles et al., 2014). Sangamanatha et al. (2012) included different age groups in their study sample. Their study, however, only included child musicians (mean age of 12.6 years) compared to child non-musicians (mean age = 12.89 years) and adult non-musicians (mean age of 24.30 years). It is possible that the musician advantage can only be seen in the young musician population, perhaps due to children's developing brain and neural pathways, such as the study conducted by Sangamanatha et al. (2012) or Benítez-Barrera et al. (2022), or only in the older musician population (Zendel & Alain, 2012; Merten et al., 2021). Musical experience may improve cognitive reserve, which enables musicians to perform better in auditory processing tasks (Zendel & Alain, 2012; Merten et al., 2021). Sangamanatha et al. (2012) also conducted another temporal resolution test, namely the Random Gap Detection test (RGDT). According to Iliadou et al. (2014), the GIN test, compared to the RGDT, may be a better and perhaps the only test to use to determine gap detection or temporal resolution. The RGDT has been suggested to possibly assess a process requiring auditory fusion and gap detection (Iliadou et al., 2014).

Donai and Jennings (2016) determined the enhanced temporal resolution performances in young (mean age 22-23 years) musicians, compared to non-musicians with normal hearing, using the GIN test. The researchers strictly controlled the amount of musical experience in both groups, so there was a maximum separation

© University of Pretoria

between the non-musician and the musician group. This current study had participants in the non-musician group that had none or minimal (< 3 years) musical experience during their lifetime. The study by Donai and Jennings (2016) only included participants with musical experience in the non-musician group if the participants had musical experience before the age of 7 years.

In terms of speech recognition in noise, the musicians in this study performed slightly better, although the difference was not statistically significant, in the DIN test. The mean SRT scores in the musician and non-musician groups for the homophasic listening condition were -10.77 dB SNR (SD = 0.56) and –10.91 dB SNR (SD = 0.68), respectively. For the out-phase listening condition, the musician group obtained a mean SRT score of -18.44 dB SNR (SD = 1.86), and the non-musician obtained a mean SRT score of -18.64 dB SNR (SD = 1.23). De Sousa et al. (2020) conducted a study on normal-hearing (PTA < 15 dB) adults, aged between 18 and 67 years, and showed mean DIN SRT thresholds of -11.1 (SD = 0.8) dB SNR and -18.4 (SD = 1.4) dB SNR for phasic and antiphasic listening conditions, respectively. Previous studies (Ruggles et al., 2014; Anaya et al., 2016; Zhang et al., 2019) also found no significant differences between musicians and non-musicians in speech recognition in noise tests. However, these studies used different speech recognition in noise tests, for example the HINT, PRESTO (Anaya et al., 2016), and QuickSIN (Ruggles et al., 2014; Zhang et al., 2019) tests, where cognition and linguistic skills may play a role in speech recognition in noise performances, by contributing to top-down processing, including interpretation based on experiences and knowledge, in understanding speech in noise (Smits et al., 2013). By using the DIN test, an increasingly popular, quick, and easy speech recognition in noise test, and presenting only the numbers 0 up to 9 in speech-weighted masking noise, one can minimize the possibility for interference from other skills that can assist with speech recognition in noise, such as cognitive skills, or linguistic skills which depends on top-down processing (Smits et al., 2013; De Sousa et al., 2022).

Additionally, using the two DIN test paradigms, the BILD was calculated per participant by using the obtained DIN SRT thresholds. In this study, there were no significant differences between the two groups. The mean BILD SRT threshold in the musician and non-musician groups were 7.67 dB SNR (SD = 1.79) and 7.73 dB SNR (SD =

© University of Pretoria

1.28), respectively. Previous studies (Goverts & Houtgast, 2010; Wolmarans et al., 2021) have reported a BILD (words presented in broadband noise masker) of 5-8 dB for normal hearing listeners. The non-musician group performed slightly, but not significantly, better than the musician group. Similarly, in the study by Zhang et al. (2019), the musician group presented with a smaller BILD value than the non-musician group. A larger BILD value indicates better unmasking abilities. It would be beneficial to determine the BILD performance in a much larger group of musicians than non-musicians (Zhang et al., 2019). To our knowledge, no other research has been done on the BILD performance between musicians and non-musicians. BILD performances may be used to determine central auditory functions (Musiek & Chermak, 2015; Zhang et al., 2019) and predict speech recognition in noise performances. Binaural hearing can be assessed by using the BILD measure (Neher, 2017). Should there be an abnormal BILD, there may be possible asymmetrical hearing problems (Neher, 2017). Parbery-Clark et al. (2013) also suggested that musical input from an early age, and continuous musical input throughout adulthood, may contribute to improved binaural hearing abilities.

One particular point to note is the duration of exposure musicians have to high sound levels for prolonged periods (Kardous et al., 2015). These high-intensity sounds that musicians may be exposed to may exceed the recommended exposure limit (REL) that is considered safe for listening and hearing, which is 85 dB(A) over 8 hours (National Institute for Occupational Safety and Health [NIOSH], 1998; Kardous et al., 2015). Due to this exposure, musicians may be prone to noise-induced hearing loss, or rather music-induced hearing loss (Kardous et al., 2015; Tufts & Skoe, 2018). Summarising, recent evidence demonstrate that hearing beyond the conventional 0.25 to 8kHz frequency range affects speech understanding in noise (Le Prell et al., 2013; Rodríguez Valiente et al., 2014; Liberman et al., 2016; Wang et al., 2021). Interestingly, Zhang et al. (2019) was the only study to our knowledge that conducted EHF audiometry in a study that determined the higher-level auditory functions of musicians. Zhang et al. (2019), a study that also assessed higher-level auditory functions in musicians compared to non-musicians, mentioned that to assess musicians' higher-level auditory functions, one must make sure of hearing thresholds that may affect the performance on higher-level auditory functions, especially because of musicians being prone to elevated hearing thresholds due to high-level noise

© University of Pretoria

exposure (Kardous et al., 2015; Tufts & Skoe, 2018). In our study, all participants had normal hearing in the conventional audiometric range. Given the growing emphasis on the role of EHF audiometry on speech recognition performance, EHF was also compared, and was not meaningfully different between the two groups. Both groups, however, have participants (72/160 ears) with increased thresholds (>15dB) at 16 kHz. Similarly, in a study conducted by Wang et al. (2021) that determined age-specific EHF thresholds, the group aged between 21-30 years presented with a slight decrease in the frequencies from 12.5 to 16 kHz.

This study could not find any significant differences between musicians and non-musicians in terms of temporal resolution and speech in noise performances. This study was homogenous in terms of the ages included, which is a limitation of this study. According to Ruggles et al. (2014), the musician advantage can only truly be seen with young participants (e.g. Anand et al., 2017) or older adult musicians (40 > years) (Zendel & Alain, 2012), and not so often with the young adult population. It would be beneficial to repeat a similar study, including EHF audiometry with a more representative sample of age groups across the board.

3.7. Acknowledgements

The authors would like to thank all the participants who were willing to participate in this study. The authors thank Professor Marien Graham for assisting with statistical analysis and Professor Clorinda Panebianco for assisting in recruiting the musician participants.

3.8. Data availability statement

The raw datasets collected, generated and analyzed during the current study are available from the authors on a reasonable request.

3.9. References

Anand, K., Mohan, K. M., & Yeraguntla, K. (2017). Auditory processing abilities in amateur musicians. *International Journal of Disability and Human Development., 16*(1), 105-113. https://doi.org/10.1515/ijdhd-2016-0038

© University of Pretoria

Anaya, E. M., Pisoni, D. B., & Kronenberger, W.G. (2016). Long-term musical experience and auditory and visual perceptual abilities under adverse conditions. *Journal of the Acoustical Society of America, 140*(3), 2074-2081. https://doi.org/10.1121/1.4962628

Benítez-Barrera, C. R., Skoe, E., Huang, J., & Tharpe, A.M. (2022). Evidence for a musician speech-perception-in-noise advantage in school-age children. *Journal of Speech, Language, and Hearing Research, 65*, 3996–4008. https://doi.org/10.1044/2022_JSLHR-22-00134

Bidelman, G. M., & Yoo, J. (2020). Musicians show improved speech segregation in competitive, multi-talker cocktail party scenarios. *Front. Psychol., 11*. https://doi.org/10.3389/fpsyg.2020.01927

Boebinger, D., Evans, S., Rosen, S., Lima, C.F., Manly, T., & Scott, S. K. (2015). Musicians and non-musicians are equally adept at perceiving masked speech. *The Journal of the Acoustical Society of America, 137*, 378–387. https://doi.org/10.1121/1.4904537

Bornman, M., Swanepoel, D., Biagio de Jager, L., & Eikelboom, R. (2019). Extended high frequency smartphone audiometry: Validity and reliability. *Journal of American Academy of Audiology, 30*, 217-226. https://doi.org/10.3766/jaaa.17111

Braga, B. H. C., Pereira, L.D., & Dias, K.Z. (2015). Normality tests of temporal resolution: Random gap detection test and gaps-in-noise.

Brink, H., van der Walt, C., & van Rensburg, G. (2018). *Fundamentals of research methodology for healthcare professionals* (4th ed.). Juta & Company (PTY).

De Sousa, K. C., Swanepoel, D., Moore, D. R, Myburgh, H. C., & Smits, C. (2020). Improving sensitivity of the digits in noise test using antiphasic stimuli. *Ear and Hearing, 41*(2), 442-450. https://doi.org/10.1097/AUD.0000000000000775

De Sousa, K. C., Smits, C., Moore, D. R., Myburgh, H., & Swanepoel, D. (2022). Diotic and antiphasic digits-in-noise testing as a hearing screening and triage tool to

© University of Pretoria

classify type of hearing loss. *Ear & Hearing, 43*(3), 1037-1048. https://doi.org/10.1097/AUD.0000000000001160

Donai, J. J., & Jennings, M. B. (2016). Gaps-in-noise detection and gender identification from noise-vocoded vowel segments: Comparing performance of active musicians to non-musicians. *The Journal of the Acoustical Society of America*, *139*(5), EL128-EL134.

Escobar, J., Mussoi, B.S., & Silberer, A.B. (2020). The effect of musical training and working memory in adverse listening situations. *Ear & Hearing, 41*, 278-288. https://doi.org/10.1097/AUD.0000000000000754

Field, A. (2018). *Discovering statistics using IBM SPSS statistics.* (5th ed.). SAGE.

Goverts, S. T., & Houtgast, T. (2010). The binaural intelligibility level difference in hearing-impaired listeners: The role of supra-threshold deficits. *Journal of the Acoustical Society of America, 127*(5), 3073-3084. https://doi.org/10.1121/1.3372716

Grassi, M., Meneghetti, C., Toffalini, E., & Borella, E. (2017). Auditory and cognitive performance in elderly musicians and non-musicians. *PLoS ONE, 12*(11). https://doi.org/10.1371/journal.pone.0187881

Hennessy, S., Mack, W. J., & Habibi, A. (2022). Speech-in-noise perception in musicians and non-musicians: a multi-level meta-analysis. *Hearing Research, 416*, 108442–108442. https://doi.org/10.1016/j.heares.2022.108442

Ho, C., Li, P., Chiang, Y., Young, S., & Chu, W. (2015). The binaural masking-level difference of Mandarin tone detection and the binaural intelligibility-level difference of Mandarin tone recognition in the presence of speech-spectrum noise. *PLoS ONE, 10*(4). https://doi.org/10.1371/journal.pone.0120977

Hunter, L. L., Monson, B. B., Moore, D. R., Sumitrajit, D., Wright, B. A., Munro, K.J., Zadeh, L. M., Blankenship, C. M., Stiepan, S. M., & Siegel, J. H. (2020). Extended high frequency hearing and speech perception implications in adults and children. *Hearing Research*. https://doi.org/10.1016/j.heares.2020.107922

© University of Pretoria

Iliadou, V., Bamiou, D., Chermak, G. D., & Nimatoudis, I. (2014). Comparison of two tests of auditory temporal resolution in children with central auditory processing disorder, adults with psychosis, and adult professional musicians. *International Journal of Audiology, 53*(8), 507-513. https://doi.org/10.3109/14992027.2014.900576

Iliadou, V.V., Bamiou, D., Sidiras, C., Moschopoulos, N. P., Tsolaki, M., Nimatoudis, I., & Chermak, G. D. (2017). The use of the gaps-in-noise test as an index of the enhanced left temporal cortical thinning associated with the transition between mild cognitive impairment and Alzheimer's disease. *Journal of the American Academy of Audiology ., 28*(5), 463-471. https://doi.org/10.3766/jaaa.16075

Jerger, J. (1970). Clinical experience with impedance audiometry. *Archives of Otolaryngology – Head and Neck Surgery, 4*(92), 311-324. https://doi.org/10.1001/archotol.1970.04310040005002

Kardous, C., Themann, C., Morata, T., Reynolds, J., & Afanuh, S. (2015). Workplace solutions: Reducing the risk of hearing disorders among musicians. *DHHS (NIOSH), 184*.

Kumar, A. U., & Sangamanatha, A. V. (2011). Temporal processing abilities across different age groups. *J Am Acad Audiol., 22*(1), 5-12. https://doi.org/10.3766/jaaa.22.1.2

Le Prell, C. G., Spankovich, C., Lobarinas, E., & Griffiths, S. K. (2013). Extended high frequency thresholds in college students: Effects of recreational noise. *J Am Acad Audiol., 24*(8), 725–739. https://doi.org/10.3766/jaaa.24.8.9

Lerousseau, J. P., Hidalgo, C., & Schön, D. (2020). Musical Training for Auditory Rehabilitation in Hearing Loss. *J. Clin. Med., 9*(1058), 1-15. https://doi.org/10.3390/jcm9041058

Liberman, M. C., Epstein, M. J., Cleveland, S. S., Wang, H., & Maison, S. F. (2016). Toward a differential diagnosis of hidden hearing loss in humans. *PLoS ONE, 11*(9). https://doi.org/10.1371/journal.pone.0162726

© University of Pretoria

Madsen, S. M. K., Marschall, M., Dau, T., & Oxenham, A. J. (2019). Speech perception is similar for musicians and non-musicians across a wide range of conditions. *Scientific Reports, 9*. https://doi.org/10.1038/s41598-019-46728-1

McKay, C. M. (2021). No evidence that music training benefits speech perception in hearing-impaired listeners: A systematic review. *SAGE, 25*, 1-16. https://doi.org/10.1177/2331216520985678

Merten, N., Fischer, M.E., Dillard, L.K., Klein, B.E.K., Tweed, T.S., & Cruickshanks. (2021). Benefit of musical training for speech perception and cognition later in life. *Journal of Speech, Language, and Hearing Research, 64*, 2885–2896. https://doi.org/10.23641/asha.14825454

Monteiro, R. A. M., Nascimento, F. M., Soares, C. D., & Ferreira, M. I. D. C. (2010). Temporal resolution abilities in musicians and no musicians violinists. *International* Archives of Otorhinolaryngology*, 14*(3), 302-308.

Musiek, F. (2016). Introduction to temporal processing, its applications to CAPD, and other aspects of neuroaudiology. *AudiologyOnline*. https://www.audiologyonline.com/articles/introduction-to-temporal-processing-its-20238

Musiek, F. E., & Chermak, G. D. (2015). *Psychophysical and behavioral peripheral and central auditory tests.* (Vol. 129). https://doi.org/10.1016/B978-0-444-62630-1.00018-4

Neher, T. T. (2017). Characterizing the binaural contribution to speech-in-noise reception in elderly hearing-impaired listeners. *Journal of the Acoustical Society of America, 141*(2), 159-163. https://doi.org/10.1121/1.4976327

NIOSH. (1998). Occupational noise exposure. *DHHS (NIOSH), 126*.

Parbery-Clark, A., Andersona, S., & Kraus, N. (2013). Musicians change their tune: How hearing loss alters the neural code. *Hearing Research, 302*, 121-131. https://doi.org/10.1016/j.heares.2013.03.009

© University of Pretoria

Potgieter, J., Swanepoel, D., Myburgh, H. C., Hopper, T. C., & Smits, C. (2015). Development and validation of a smartphone-based digits-in-noise hearing test in South African English. *International Journal of Audiology, 55*, 405-411. https://doi.org/10.3109/14992027.2016.1172269

Rodríguez Valiente, A., Trinidad, A., García Berrocal, J. R., Górriz, C., & Ramírez Camacho, R. (2014). Extended high-frequency (9 – 20 kHz) audiometry reference thresholds in 645 healthy subjects. *International Journal of Audiology, 53*, 531–545. https://doi.org/10.3109/14992027.2014.893375

Ronen, M., Lifshitz-Ben-Basatb, A., Taitelbaum-Sweadb, R., & Fostick, L. (2018). Auditory temporal processing, reading, and phonological awareness among aging adults. *Acta Psychologica, 190*, 1-10. https://doi.org/10.1016/j.actpsy.2018.06.010

Ruggles, D. R., Freyman, R. L., Oxenham, A. J. (2014). Influence of musical training on understanding voiced and whispered speech in noise. *PLoS ONE, 9*(1). https://doi.org/10.1371/journal.pone.0086980

Sangamanatha, A. V., Fernandes, J., Bhat, J., Srivastava, M., & Udupa, P. S. (2012). Temporal resolution in individuals with and without musical training. *Journal of* Indian Speech and Hearing Association, 26(1), 27-35.

Skoe, E., Camera, & Tufts, J. (2019). Noise exposure may diminish the musician advantage for perceiving speech in noise. *Ear & Hearing, 40*(4), 782-793. https://doi.org/doi.org/10.1097/AUD.0000000000000665

Slater, J., & Kraus, N. (2016). The role of rhythm in perceiving speech in noise: a comparison of percussionists, vocalists and non-musicians. *Cognitive Processes, 17*, 79-87. https://doi.org/10.1007/s10339-015-0740-7

Smits, C., Goverts, S. T., & Festen, J. M. (2013). The digits-in-noise test: Assessing auditory speech recognition abilities in noise. *Journal of the Acoustical Society of America. Soc. Am., 133*(3), 1693–1706. https://doi.org/https://doi.org/10.1121/1.4789933

© University of Pretoria

Tufts, J. B., & Skoe, E. (2018). Examining the noisy life of the college musician: Weeklong noise dosimetry of music and non-music activities. *International Journal of Audiology, 57*. https://doi.org/10.1080/14992027.2017.1405289

Varnet, L., Wang, T., Peter, C., Meunier, F., & Hoen, M. (2015). How musical expertise shapes speech perception: evidence from auditory classification images. *Scientific Reports, 5*(14489). https://doi.org/10.1038/srep14489

Wang, M., Ai, Y., Han, Y., Fan, Z., Shi, P., & Wang, H. (2021). Extended high-frequency audiometry in healthy adults with different age groups. *Head and Neck Surgery, 50*(52). https://doi.org/10.1186/s40463-021-00534-w

Wolmarans, J., de Sousa, K. C., Frisby, C., Mahomed-Asmail, F., Smit, C., Moore, D. R., Swanepoel, D. (2021). Speech recognition in noise using binaural diotic and antiphasic digits-in-noise in children: Maturation and self-test validity. *Journal of the American Academy of Audiology, 32*(5), 315–323. https://doi.org/https://doi.org/10.1055/s-0041-1727274

Wong, A. C., & McPherson, B. (2015). Adaptive tests of temporal resolution: comparison with the gaps-in-noise test in normal-hearing young adults. *Int J Audiol, 54*(1), 29-36. https://doi.org/https://doi.org/10.3109/14992027.2014.952457

Yeend, I., Beach, E.F., Sharma, M., & Dillon, H. (2017). The effects of noise exposure and musical training on suprathreshold auditory processing and speech perception in noise. *Hearing Research, 353*, 224-236. https://doi.org/10.1016/j.heares.2017.07.006

Zendel, B. R., & Alain, C. (2012). Musicians experience less age-related decline in central auditory processing. *Psychology and Aging, 27*(2), 410-417. https://doi.org/10.1037/a0024816

Zhang, F., Roland, C., Rasul, D., Cahn, S., Liang, C., & Valencia, G. (2019). Comparing musicians and non-musicians in signalin-noise perception. *International Journal of Audiology, 58*(11), 717-723. https://doi.org/10.1080/14992027.2019.1623424

© University of Pretoria

Chapter 4: Discussion, clinical implications and conclusion

4.1. Overview of research findings

The goal of this study was to compare a musician participant group and a non-musician participant group with regard to their conventional audiometric thresholds and EHF audiometric thresholds (0.25 to 16 kHz), homophasic and antiphasic DIN test results, BILD results, and the GIN test results. The results indicated no group difference across all the tests.

In this study, the non-musician group had slightly, but not significantly better, GIN thresholds. The findings correlate more with the results of Monteiro et al. (2010), who also found no significant differences on GIN test performances in either left or right ears between violinist musicians and their control group, who were non-musicians matched for age (mean age of 24.6 y). A larger effect between the two groups would perhaps been noted if another age group, either a younger with a short amount of musical training or an older participant group with lifelong musical training, were included in the study (Ruggles et al., 2014).

Other literature reports the contrary, showing enhanced temporal resolution skills (Sangamanatha et al., 2012; Donai & Jennings, 2016). Sangamanatha et al. (2012) included different age groups in their study sample. Their study, however, only included child musicians (mean age of 12.6 years) compared to child non-musicians (mean age = 12.89 years) and adult non-musicians (mean age of 24.30 years). It is possible that the musician advantage can only be seen in the young musician population, perhaps due to children's developing brain and neural pathways, such as the study conducted by Sangamanatha et al. (2012) or Benítez-Barrera et al. (2022), or only in the older musician population (Merten et al., 2021; Zendel & Alain, 2012). Musical experience may improve cognitive reserve, which enables musicians to perform better in auditory processing tasks (Merten et al., 2021; Zendel & Alain, 2012). Sangamanatha et al. (2012) also conducted another temporal resolution test, namely the random gap detection test (RGDT). According to Iliadou et al. (2014), the GIN test, compared to the RGDT, may be a better, and perhaps the only test to use to determine gap detection, or temporal resolution. We also know that the GIN test has

© University of Pretoria

very low cognitive demands, in comparison with the other temporal resolution tests (Iliadou et al., 2017). The RGDT has been suggested to possibly test a process requiring auditory fusion and gap detection (Iliadou et al., 2014).

Donai and Jennings (2016) determined the enhanced temporal resolution performances in young musicians (mean age 22-23 years), compared to non-musicians with normal hearing using the GIN test. The researchers strictly controlled the amount of musical experience in both groups so that the groups differed in terms of musical experience. The current study had participants in the non-musician group that had none, or very little musical (< 3 years) experience during their lifetime. The study conducted by Donai and Jennings (2016) only included participants with musical experience in the non-musician group if the participants received musical training before the age of 7 years. It would be beneficial to conduct a longitudinal study on musicians of various ages to determine the effect of various lengths of musical experience on temporal resolution abilities.

In terms of speech recognition in noise, the musicians in this study performed slightly better, although the difference was not statistically significant. The mean SRT scores in the musician group and non-musician group for the homophasic listening condition were -10.77 dB SNR (SD = 0.56) and –10.91 dB SNR (SD = 0.68), respectively. For the antiphasic listening condition, the musician group obtained a mean SRT score of -18.44 dB SNR (SD = 1.86), and the non-musician obtained a mean SRT score of -18.64 dB SNR (SD = 1.23). De Sousa et al. (2020) conducted a study on normal-hearing (PTA < 15 dB) adults, aged between 18 and 67 years, and determined mean DIN SRT thresholds to be -11.1 (SD = 0.8) dB SNR and -18.4 (SD = 1.4) dB SNR for homophasic and antiphasic listening conditions, respectively. The better antiphasic listening condition results may be due to the ‘antiphasic advantage’, where binaural integration is key to separating spatial cues from interfering noise (de Sousa et al., 2020). Testing in an antiphasic listening condition, compared to the homophasic listening condition, proved to be more sensitive to hearing loss (De Sousa et al., 2020).

Previous studies (e.g., Zhang et al., 2019; Ruggles et al., 2014; Anaya et al., 2016) also found no significant differences between musicians and non-musicians in speech recognition in noise tests. However, these studies used different speech recognition

© University of Pretoria

in noise tests, for example the HINT, PRESTO (Anaya et al., 2016), and the QuickSIN (Ruggles et al., 2014; Zhang et al., 2019) tests, where cognition and linguistic skills might have played a role in speech recognition in noise performances, by contributing to top-down processing, including interpretation based on experiences and knowledge, in understanding speech in noise (Smits et al., 2013). By using the DIN test, dependant on bottom-up processing, and an increasingly popular, quick, and easy speech recognition in noise test, and presenting only the numbers 0 up to 9 in speech-weighted masking noise, one can minimise the possibility for interference from other skills that can assist with speech recognition in noise, such as cognitive skills, or linguistic skills which depends on top-down processing (De Sousa et al., 2022; Smits et al., 2013). Moreover, the DIN test is independent of language (Low et al., 2018) and can be presented in English as the participant's proficiency in English does not influence the test results (Low et al., 2018).

Furthermore, the participants of this current study were all students with a tertiary educational background. One can assume that this study's participants were on the same educational, cognitive, and linguistic level, and that these variables would not have caused differences regarding auditory performances. However, it would be beneficial to test for cognition and linguistic competency with formal tests when determining the differences in auditory performance between musicians and non-musicians. Interestingly, Benítez-Barrera et al. (2022) conducted a study on young school-aged musicians compared to non-musicians on their performances, and also tested for intelligence. The authors found no difference between the two groups on intelligence, nor a link between intelligence and musical experience. However, when Merten et al. (2021) conducted a study on older adult musicians and their speech recognition in noise abilities later in life, they concluded that musical experience through life may decrease cognitive decline. Further testing needs to be done regarding intelligence, cognition and perhaps linguistic knowledge when researching musicians and the 'musician advantage'.

The BILD was determined per participant using the values obtained from the homophasic and antiphasic listening conditions. BILD refers to binaural hearing and binaural unmasking abilities (Neher, 2017). Binaural unmasking refers to the ability to suppress the effect of masking in difficult listening situations, where interfering noise

© University of Pretoria

is present (Gibbs et al., 2022). In this study, there were no significant differences between the two groups. The mean BILD SRT thresholds of the musician group compared to the non-musician group were 7.67 dB SNR (SD = 1.79) and 7.73 dB SNR (SD = 1.28), respectively. For normal hearing listeners, a BILD of 5-8 dB would be expected (Goverts & Houtgast, 2010; Wolmerans et al., 2021). A larger BILD value compared to a smaller BILD value indicates better unmasking abilities, or in other words, improved abilities to listen to a target sound instead of interfering background noise. Likewise, in the study by Zhang et al. (2019), the non-musician participant group performed slightly, but not significantly better, than the musician group. To our knowledge, no other research has been done on the BILD performance between musicians and non-musicians. It would be beneficial to determine the BILD performance in a much larger group of musicians than non-musicians (Zhang et al., 2019). BILD has become a predictor of speech recognition in noise performances, or central auditory functions (Zhang et al., 2019; Musiek & Chermak, 2015). Should there be abnormal BILD results (i.e., BILD results less or more than 5-8 dB), there may be possible asymmetrical hearing problems (Neher, 2017). Parbery-Clark et al. (2013) suggested that musical input from an early age, and the continuous musical input throughout adulthood, may contribute to improved binaural hearing abilities.

The current study specifically performed pure tone audiometry to include participants with normal hearing to exclude the possibility of a peripheral MIHL that might interfere with higher-level auditory performances as musicians may be exposed to high sound levels for prolonged periods (Kardous et al., 2015). These high-intensity sound levels may exceed the recommended exposure limit (REL), considered safe for listening and hearing. According to the National Institute for Occupational Safety and Health (NIOSH, 1998), the REL is 85 dB(A) over a period of 8 hours. Due to this exposure, musicians may be prone to noise-induced hearing loss, or rather music-induced hearing loss (Kardous et al., 2015; Tufts & Skoe, 2018). Zhang et al. (2019) mentioned that in order to assess musicians' higher level auditory functions, researchers should ensure that the hearing thresholds of participants that can possibly affect their performance on higher level auditory tests should be considered in their research and interpretation of research results (Kardous et al., 2015; Tufts & Skoe, 2018). Moreover, recent evidence demonstrates that hearing beyond the conventional 0.25 to 8 kHz frequency range affects speech understanding in noise (Le Prell et al., 2013;

© University of Pretoria

Liberman et al., 2016; Rodríguez Valiente et al., 2016; Wang et al., 2021). Deficits in EHF thresholds (>8 kHz), even when the conventional audiometric range (0.25 – 8 kHz) thresholds are in the normative range, may contribute to poor speech in noise understanding (Motlagh Zadeh et al., 2019; Rodríguez Valiente et al., 2016). For this reason, research suggests that EHF audiometry should be part of routine audiometric testing. In the current study, both the musician and non-musician participants had normal hearing in the conventional audiometric range. Given the growing emphasis on the role of EHF audiometry on speech recognition performance, EHF was also compared to determine the EHF hearing abilities of musicians, but there were no significant differences between the two participant groups. Both participant groups, however, included participants (72/160 ears) with increased thresholds (> 15 dB) at 16 kHz. Similarly, in a large study conducted by Wang et al. (2021) that determined age-specific EHF thresholds, the group aged between 21 to 30 years presented with slightly poorer thresholds in the frequencies from 12.5 to 16 kHz. Interestingly, Zhang et al. (2019), a study that also assessed higher-level auditory functions in musicians compared to non-musicians, was the only study to our knowledge who conducted EHF audiometry in a study that determined higher level auditory functions in musicians.

4.2. Clinical implications of the study

The current study did not find any significant differences across all tests in the musician participant group compared to the non-musician participant group. However, the obtained results add to the growing body of literature on the 'musician advantage' this population may have when performing in auditory tasks. Furthermore, this study concluded that future studies should consider including different age groups to determine if the musician advantage is present in a specific age group, as different results could not be yielded with regards to speech recognition in noise and temporal resolution abilities in young adult musician participants compared to the non-musician participant group.

4.3. Critical evaluation

4.3.1. Strengths of the study

The current study included a reasonable sample size (n = 80), allowing for more accurate deductions of the target population. Also, the two participant groups were

© University of Pretoria

age- and gender-matched to limit confounding variables. This research design allowed for detailed, accurate and objective interpretation of test results. Valid and reliable tests were used for participant selection and data collection procedures (Bornman et al., 2019; Iliadou et al., 2014; Potgieter et al., 2015).

4.3.2. Limitations of the study

The current study only included young adults (aged between 18 and 30 years) participants. According to Ruggles et al. (2014), the musician advantage can only be truly seen with the school-aged musicians (e.g., Anand et al., 2017) and older adult musicians (40 > years) (Zendel & Alain, 2012), and not so often with the young adult population. Despite this study only including participants who were university students, this study did not test for cognition. Some literature suggests that cognition, or linguistic knowledge, may play a significant role in speech recognition in noise tests (De Sousa et al., 2022; Smits et al., 2013). McKay (2021) also concluded that future evidence needs to make sure that when studying musicians and non-musicians, researchers should include tests that differentiate the effects of musical training from perceptual and cognitive abilities, including linguistic knowledge.

4.4. Recommendations for future research

Since this study only included a group of young adults to participate, the results of this study may not be generalised to populations with other characteristics, such as younger or older age. It would be beneficial to repeat the current study, including EHF audiometry, temporal resolution, DIN and BILD tests, with a sample consisting of different age groups, for example, a young, school age participant group, a young adult participant group, and an older adult participant group, compared to age-and gender matched musicians. Furthermore, future studies researching the effect of musical experience on auditory performances compared to non-musicians need to test for cognition. Finally, it would be necessary for future studies to include EHF audiometry in their test battery when comparing musicians and non-musicians due to the effect EHF thresholds may have on auditory performances (Zhang et al., 2019).

4.5. Conclusion

The current study could not find any significant differences between musician participants and non-musician participants in terms of temporal resolution and speech

© University of Pretoria

in noise performances. The musician group, however, performed slightly, not significantly, better across all tests, except with the BILD test results, where the non-musicians performed better, although not significantly better. The results of the study may suggest that the inclusion of different age groups, or musician groups with different lengths of musical training or experience might be beneficial in a study with musician participants and non-musician participants.

© University of Pretoria

References

Accessible Law. (2020). *Protection of personal information act (POPIA Act)*. https://popia.co.za/

Anand, K., Mohan, K.M., & Yeraguntla, K. (2017). Auditory processing abilities in amateur musicians. *International Journal on Disability and Human Development, 16*(1), 105-113. https://doi.org/DOI 10.1515/ijdhd-2016-0038

Anaya, E. M., Pisoni, D.B., & Kronenberger, W.G. (2016). Long-term musical experience and auditory and visual perceptual abilities under adverse conditions. *Journal of the Acoustical Society of America, 140*(3), 2074-2081. https://doi.org/10.1121/1.4962628

Association, A. S.-L.-H. (2020). *Degree of hearing loss*. ASHA - American Speech-Language-Hearing Association. https://www.asha.org/public/hearing/degree-of-hearing-loss/

Benítez-Barrera, C. R., Skoe, E., Huang, J., & Tharpe, A.M. (2022). Evidence for a musician speech-perception-in-noise advantage in school-age children. *Journal of Speech, Language, and Hearing Research, 65*, 3996–4008. https://doi.org/10.1121/1.4962628

Bidelman, G. M., & Yoo, J. (2020). Musicians show improved speech segregation in competitive, multi-talker cocktail party scenarios. *Frontiers in Psychology, 11*. https://doi.org/10.3389/fpsyg.2020.01927

Boebinger, D., Evans, S., Rosen, S., Lima, C.F., Manly, T., & Scott, S.K. (2015). Musicians and non-musicians are equally adept at perceiving masked speech. *The Journal of the Acoustical Society of America, 137*, 378–387. https://doi.org/10.1121/1.4904537

Bornman, M., Swanepoel, D., Biagio de Jager, L., & Eikelboom, R. (2019). Extended high frequency smartphone audiometry: Validity and reliability. *Journal of American Academy of Audiology, 30*, 217-226. https://doi.org/10.3766/jaaa.17111

© University of Pretoria

Braga, B. H. C., Pereira, L.D., & Dias, K.Z. (2015). Normality tests of temporal resolution: Random gap detection test and gaps-in-noise.

Brink, H., van der Walt, C., & van Rensburg, G. (2018). *Fundamentals of Research Methodology for Healthcare Professionals* (4 ed.). Juta and Company (PTY) Ltd.

De Sousa, K. C., Swanepoel, D., Moore, D.R, Myburgh, H.C., & Smits, C. (2020). Improving sensitivity of the digits in noise test using antiphasic stimuli. *Ear and Hearing, 41*(2), 442-450. https://doi.org/10.1097/AUD.0000000000000775

De Sousa, K. C., Smits, C., Moore, D.R., Myburgh, H., & Swanepoel, D. (2022). Diotic and antiphasic digits-in-noise testing as a hearing screening and triage tool to classify type of hearing loss. *Ear and Hearing, 43*(3), 1037-1048. https://doi.org/10.1097/AUD.0000000000001160

Donai, J. J., & Jennings, M. J. (2016). Gaps-in-noise detection and gender identification from noise-vocoded vowel segments: Comparing performance of active musicians to non-musicians. *The Journal of the Acoustical Society of America, 139*(5). https://doi.org/10.1121/1.4947070

Edmonds, W. A., & Kennedy, T.D. (2016). *An applied guide to research designs: Quantitative, qualitative, and mixed methods* (2 ed.). SAGE Publications, Inc.

Escobar, J., Mussoi, B.S., & Silberer, A.B. (2020). The effect of musical training and working memory in adverse listening situations. *Ear and Hearing, 41*, 278-288. https://doi.org/10.1097/AUD.0000000000000754

Field, A. (2018). *Discovering statistics using IBM SPSS statistics.* (5th ed.). SAGE.

Filippini, R., Wong, B., Schochat, E., & Musiek, F. (2020). GIN test: A meta-analysis on its neurodiagnostic value. *Journal of the American Academy of Audiology, 31*(2), 147-157. https://doi.org/10.3766/jaaa.18079

Gibbs, B. E., Bernstein, J.G.W., Burngart, D.S., & Goupell, M.J. (2022). Effects of better-ear glimpsing, binaural unmasking, and spectral resolution on spatial release from masking in cochlear-implant users. *The Journal of the Acoustical*

© University of Pretoria

Society of America, 152(1230). https://doi-org.uplib.idm.oclc.org/10.1121/10.0013746

Goverts, S. T., & Houtgast, T. (2010). The binaural intelligibility level difference in hearing-impaired listeners: The role of supra-threshold deficits. *Journal of the Acoustical Society of America, 127*(5), 3073-3084. https://doi.org/10.1121/1.3372716

Grassi, M., Meneghetti, C., Toffalini, E., & Borella, E. (2017). Auditory and cognitive performance in elderly musicians and nonmusicians. *PLoS ONE, 12*(11). https://doi.org/10.1371/journal.pone.0187881

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative research. *Evidence-Based Nursing, 18*, 66-67. https://doi.org/10.1136/eb-2015-102129

Hennessy, S., Mack, W. J., & Habibi, A. (2022). Speech-in-noise perception in musicians and non-musicians: a multi-level meta-analysis. *Hearing Research, 416*, 108442–108442. https://doi.org/10.1016/j.heares.2022.108442

Ho, C., Li, P., Chiang, Y., Young, S., & Chu, W. (2015). The binaural masking-level difference of Mandarin tone detection and the binaural intelligibility-level difference of Mandarin tone recognition in the presence of speech-spectrum noise. *PLoS ONE, 10*(4). https://doi.org/10.1371/journal.pone.0120977

Hunter, L. L., Monson, B. B., Moore, D. R., Sumitrajit, D., Wright, B. A., Munro, K. J., Zadeh, L. M., Blankenship, C. M., Stiepan, S. M., & Siegel, J. H. (2020). Extended high frequency hearing and speech perception implications in adults and children. *Hearing Research*. https://doi.org/10.1016/j.heares.2020.107922

Iliadou, V., Bamiou, D., Chermak, G.D., & Nimatoudis, I. (2014). Comparison of two tests of auditory temporal resolution in children with central auditory processing disorder, adults with psychosis, and adult professional musicians. *International Journal of Audiology, 53*(8), 507-513. https://doi.org/10.3109/14992027.2014.900576

Iliadou, V. V., Bamiou, D., Sidiras, C., Moschopoulos, N.P., Tsolaki, M., Nimatoudis, I., & Chermak, G.D. (2017). The use of the gaps-in-noise test as an index of the

© University of Pretoria

enhanced left temporal cortical thinning associated with the transition between mild cognitive impairment and Alzheimer's disease. *Journal of the American Academy of Audiology, 28*(5), 463-471. https://doi.org/10.3766/jaaa.16075

Interacoustics. (2016). *High Frequency Audiometry*. https://www.interacoustics.com/guides/test/audiometry-tests/high-frequency-audiometry

Jerger, J. (1970). Clinical experience with impedance audiometry. *Archives of Otolaryngology – Head and Neck Surgery, 4*(92), 311-324. https://doi.org/10.1001/archotol.1970.04310040005002

Kardous, C., Themann, C., Morata, T., Reynolds, J., & Afanuh, S. (2015). Workplace solutions: Reducing the risk of hearing disorders among musicians. *DHHS (NIOSH), 184*.

Kumar, A. U., & Sangamanatha, A.V. (2011). Temporal processing abilities across different age groups. *Journal of the American Academy of Audiology, 22*(1), 5-12. https://doi.org/10.3766/jaaa.22.1.2

Kumar, P., Sanju, H.K., & Nikhil, J. (2016). Temporal resolution and active auditory discrimination skill in vocal musicians. *International Archives of Otorhinolaryngology, 20*(4). https://doi.org/10.1055/s-0035-1570312

Le Prell, C. G., Spankovich, C., Lobarinas, E., & Griffiths, S.K. (2013). Extended high frequency thresholds in college students: Effects of recreational noise. *Journal of the American Academy of Audiology, 24*(8), 725–739. https://doi.org/10.3766/jaaa.24.8.9

Lerousseau, J. P., Hidalgo, C., & Schön, D. (2020). Musical Training for Auditory Rehabilitation in Hearing Loss. *Journal of Clinical Medicine, 9*(1058), 1-15. https://doi.org/10.3390/jcm9041058

Liberman, M. C., Epstein, M.J., Cleveland, S.S.,Wang, H., & Maison, S.F. (2016). Toward a differential diagnosis of hidden hearing loss in humans. *PLoS ONE, 11*(9). https://doi.org/10.1371/journal.pone.0162726

© University of Pretoria

Low, D., Sajeniouk, V., & Kuroiwa Rivero, M. (2018). The digits-in-noise test: Overcoming the language barrier in audiometric testing. *Journal of Hearing Science, 8*(2), 366.

Madsen, S. M. K., Marschall, M., Dau, T., & Oxenham, A.J. (2019). Speech perception is similar for musicians and non-musicians across a wide range of conditions. *Scientific Reports, 9*. https://doi.org/10.1038/s41598-019-46728-1

McKay, C. M. (2021). No evidence that music training benefits speech perception in hearing-impaired listeners: A systematic review. *SAGE, 25*, 1-16. https://doi.org/10.1177/2331216520985678

Merten, N., Fischer, M.E., Dillard, L.K., Klein, B.E.K., Tweed, T.S., & Cruickshanks. (2021). Benefit of musical training for speech perception and cognition later in life. *Journal of Speech, Language, and Hearing Research, 64*, 2885–2896. https://doi.org/10.23641/asha.14825454

Monteiro, R. A. M., Nascimento, F.M., Soares, C.D., & Ferreira, M.I.D.C. (2010). Temporal resolution abilities in musicians and no musicians violinists. *International Archives of Otorhinolaryngology, 14*(3), 302-308.

Motlagh Zadeh, L., Silbert, N.H., Sternastya, K., Swanepoel, D., Hunter, L. L., & Moore, D.R. (2019). Extended high-frequency hearing enhances speech perception innoise. *PNAS, 116*(47), 23753–23759. https://doi.org/10.1073/pnas.1903315116

Musiek, F. (2016). Introduction to temporal processing, its applications to CAPD, and other aspects of neuroaudiology. *AudiologyOnline*. https://www.audiologyonline.com/articles/introduction-to-temporal-processing-its-20238

Musiek, F. E., & Chermak, G.D. (2015). *Psychophysical and behavioral peripheral and central auditory tests.* (Vol. 129). https://doi.org/10.1016/B978-0-444-62630-1.00018-4

© University of Pretoria

Neher, T. T. (2017). Characterizing the binaural contribution to speech-in-noise reception in elderly hearing-impaired listeners. *Journal of the Acoustical Society of America, 141*(2), 159-163. https://doi.org/10.1121/1.4976327

NIOSH. (1998). Occupational noise exposure. *Department of Health and Human Services (NIOSH), 126*.

Parbery-Clark, A., Andersona, S., & Kraus, N. (2013). Musicians change their tune: How hearing loss alters the neural code. *Hearing Research, 302*, 121-131. https://doi.org/10.1016/j.heares.2013.03.009

Patel, A. D. (2014). The evolutionary biology of musical rhythm: Was Darwin wrong? *PLOS Biology, 12*(5). https://doi.org/10.1371/journal.pbio.1001821

Potgieter, J., Swanepoel, D., Myburgh, H.C., Hopper, T.C., & Smits, C. (2015). Development and validation of a smartphone-based digits-in-noise hearing test in South African English. *International Journal of Audiology, 55*, 405-411. https://doi.org/10.3109/14992027.2016.1172269

Rodríguez Valiente, A., Trinidad, A., García Berrocal, J.R., Górriz, C., & Ramírez Camacho, R. (2014). Extended high-frequency (9 – 20 kHz) audiometry reference thresholds in 645 healthy subjects. *International Journal of Audiology, 53*, 531–545. https://doi.org/10.3109/14992027.2014.893375

Ronen, M., Lifshitz-Ben-Basatb, A., Taitelbaum-Sweadb, R., & Fostick, L. (2018). Auditory temporal processing, reading, and phonological awareness among aging adults. *Acta Psychologica, 190*, 1-10. https://doi.org/10.1016/j.actpsy.2018.06.010

Ruggles, D. R., Freyman, R.L., Oxenham, A.J. (2014). Influence of musical training on understanding voiced and whispered speech in noise. *PLoS ONE, 9*(1). https://doi.org/10.1371/journal.pone.0086980

Sangamanatha, A. V., Fernandes, J., Bhat, J., Srivastava, M., & Udupa, P.S. (2012). Temporal resolution in individuals with and without musical training. *Journal of Indian Speech and Hearing Association, 26*(1), 27-35.

© University of Pretoria

Slater, J., & Kraus, N. (2016). The role of rhythm in perceiving speech in noise: a comparison of percussionists, vocalists and non-musicians. *Cognitive Processing, 17*, 79-87. https://doi.org/10.1007/s10339-015-0740-7

Smits, C., Goverts, S.T., & Festen, J.M. (2013). The digits-in-noise test: Assessing auditory speech recognition abilities in noise. *Journal of the Acoustical Society of America, 133*(3), 1693–1706. https://doi.org/10.1121/1.4789933

Stach, B. (2010). *Clinical audiology: An introduction* (2 ed.). Cengage Learning.

Tufts, J. B., & Skoe, E. (2018). Examining the noisy life of the college musician: Weeklong noise dosimetry of music and non-music activities. *International Journal of Audiology, 57*. https://doi.org/10.1080/14992027.2017.1405289

Varnet, L., Wang, T., Peter, C., Meunier, F., & Hoen, M. (2015). How musical expertise shapes speech perception: evidence from auditory classification images. *Scientific Reports, 5*(14489). https://doi.org/10.1038/srep14489

Wang, M., Ai, Y., Han, Y., Fan, Z., Shi, P., & Wang, H. (2021). Extended high-frequency audiometry in healthy adults with different age groups. *Head and Neck Surgery, 50*(52). https://doi.org/10.1186/s40463-021-00534-w

Wolmarans, J., de Sousa, K.C., Frisby, C., Mahomed-Asmail, F., Smit, C., Moore, D.R., Swanepoel, D. (2021). Speech recognition in noise using binaural diotic and antiphasic digits-in-noise in children: Maturation and self-test validity. *Journal of the American Academy of Audiology, 32*(5), 315–323. https://doi.org/10.1055/s-0041-1727274

Wong, A. C., & McPherson, B. (2015). Adaptive tests of temporal resolution: comparison with the gaps-in-noise test in normal-hearing young adults. *International Journal of Audiology, 54*(1), 29-36. https://doi.org/10.3109/14992027.2014.952457

World Health Organisation (WHO) (2020). *Templates for informed consent forms.* https://www.who.int/ethics/review-committee/informedconsent/en/

© University of Pretoria

Yeend, I., Beach, E.F., Sharma, M., & Dillon, H. (2017). The effects of noise exposure and musical training on suprathreshold auditory processing and speech perception in noise. *Hearing Research, 353*, 224-236. https://doi.org/10.1016/j.heares.2017.07.006

Zendel, B. R., & Alain, C. (2012). Musicians experience less age-related decline in central auditory processing. *Psychology and Aging, 27*(2), 410-417. https://doi.org/10.1037/a0024816

Zhang, F., Roland, C., Rasul, D., Cahn, S., Liang, C. & Valencia, G. (2019). Comparing musicians and non-musicians in signalin-noise perception. *International Journal of Audiology, 58*(11), 717-723. https://doi.org/10.1080/14992027.2019.1623424

© University of Pretoria

List of appendices

1. Appendix A: Ethical clearance
2. Appendix B: Request for participation from the Registrar
3. Appendix C: Letter to the Head of the Music Department
4. Appendix D: Informed consent
5. Appendix E: Referral letter
6. Appendix F: Plagiarism declaration
7. Appendix G: Permission letter to the Music Department
8. Appendix H: Questionnaire
9. Appendix I: Data collection sheet
10. Appendix H: Proof of submission of article

© University of Pretoria

Appendix A: Ethical clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Humanities 100
Since 1919

15 November 2021

Dear Miss MN Schoeman

Project Title: Speech recognition in noise and temporal resolution abilities of formally trained musicians

Researcher: Miss MN Schoeman

Supervisor(s): Prof ME Soer Prof L Pottas Mrs KC De Sousa

Department: Speech Language Path and Aud

Reference number: 17064041 (HUM055/0821)

Degree: Masters

I have pleasure in informing you that the above application was **approved** by the Research Ethics Committee on 15 November 2021. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should the actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

We wish you success with the project. Sincerely,

Prof Karen Harris

Chair: Research Ethics Committee Faculty of Humanities UNIVERSITY OF PRETORIA

e-mail: tracey.andrew@up.ac.za

Research Ethics Committee Members: Prof KL Harris (Chair); Mr A Bizos; Dr A-M de Beer; Dr A dos Santos; Dr P Gutura; Ms KT Govinder Andrew; Dr E Johnson; Dr D Krige; Prof D Maree; Mr A Mohamed; Dr I Noomé, Dr J Okeke; Dr C Puttergill; Prof D Reyburn; Prof M Soer; Prof E Taljard; Ms D Mokalapa

Room 7-27, Humanities Building, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa
Tel +27 (0)12 420 4853| Fax +27 (0)12 420 4501|Email pghumanities@up.ac.za | www.up.ac.za/faculty-of-humanities

© University of Pretoria

Appendix B: Request for participation from the Registrar

August 2021

Prof C Nicholson
Registrar

Dear Professor Nicholson

PERMISSION FOR STUDENTS OF THE FACULTY OF HUMANITIES TO PARTICIPATE IN RESEARCH STUDY

My name is Michèle Schoeman, and I am a registered student for a Masters degree in Audiology at the University of Pretoria. In order to complete my degree, I am required to conduct a research project. The research I wish to conduct involves the **evaluation and comparison of speech recognition and temporal resolution abilities in formally trained musicians**. This project will be conducted under the supervision of Prof. L. Pottas, Prof. M. Soer and Mrs. K. de Sousa. I hereby seek your consent to invite the students from the Faculty of Humanities at the University of Pretoria to participate in my research study. Should you provide me with permission to invite these students to participate, their participation would be entirely voluntary, and testing will not exceed 60 minutes.

Research background: Temporal processing is essential for the perception of verbal and non-verbal stimuli and can be defined as the shortest time necessary for a person to distinguish between two sounds. This ability plays an essential role in speech understanding, as it enables an individual to decode complex acoustic signals in the presence of competing background noise. Research has been suggesting that music can influence the central auditory pathway and improve speech recognition in noise. Some studies indicate that musicians outperform non-musicians with regard to their ability to recognise speech in noise. However, other studies have concluded that this musician advantage may only be evident in complex auditory tasks and that better speech recognition abilities may be due to working memory capacity, cognitive abilities, or other psychoacoustic tasks rather than musical experience. Consequently, studies have presented contradictory results, and the results remain unclear whether musicians have better speech recognition in noise compared to non-musicians. If musical expertise is beneficial for the recognition of speech in noise, music can be used to improve rehabilitation for individuals with hearing and language-related disorders. The aim of this study is to compare the temporal resolution and speech recognition abilities in different listening conditions in a sample of formally trained musicians compared to non-musicians.

Study participants: The participants will be required to present with clinically normal hearing sensitivity. One group, namely the musicians (aged 18-30 years) are required to have at least ten years of musical experience and practising consistently at least three times a week over the last three years before this study. Another group, namely the non-musicians are required to have no more than three years of musical experience over lifetime.

Ethical considerations: Ethical approval will be obtained from the Departmental Research and Ethics Committee (RESCOM) of the Department of Speech-Language Pathology and Audiology, the Research Ethics Committee of the Faculty of Humanities, the Survey Committee of the University of Pretoria, as well as the Head of the Music Department and a lecturer from the Music Department. Informed consent

© University of Pretoria

will be obtained from the participants, and an alphanumeric code will be allocated to each participant during the research study so that their results can be reported confidential. Participants will be assured that participation is voluntary and that they will be allowed to withdraw at any moment without any negative consequences

Procedures to be followed:

- Following the informed consent, a questionnaire will be provided. The questionnaire will involve questions about the participants' medical and noise exposure history. The purpose of these questions is to exclude participants who do not adhere to the selection criteria of the study.
- A set of audiological tests will be conducted at the Music Department to determine the participants' outer, middle, and inner ear function. The participant will be required to sit still during objective tests or wear headphones and press a button to respond to sound.
- The South African English Digits-in-Noise test will then be conducted. Headphones will be placed on the participants' ears and he/she will hear a series of digit-triplets. The participant will be required to respond by typing on the smartphone what he/she have heard.
- The Gaps-in-Noise test will be conducted at the Department of Speech-Language Pathology and Audiology. Headphones will be placed on the participants' ears and he/she will hear a noise with varied and randomised gaps in between. The participant will be required to report when he/she have heard the gaps.

Risks and benefits: There are no foreseeable physical discomfort or risk involved with regards to the testing procedures. Should participants feel uncomfortable, fatigue, or emotionally distressed, he/she may withdraw from the study without any negative consequences. There are, however, minimal risks involved due to COVID-19 and all COVID-19 protocols will be followed. Participants will not benefit directly from this study; however, participants will receive a free hearing test. Should participants present with any auditory difficulties or hearing loss, he/she will be referred to the Department of Speech-Language Pathology and Audiology at the University of Pretoria where further testing and early intervention and management can take place.

Data storage: Data from this research project will be digitally stored for a minimum of fifteen (15) years after completion of the original project on the University's institutional Research Data Management system, where it will be secured and conserved through the University's research data management archive system and made available through the University of Pretoria's Research Data Management Repository, if applicable. A hard copy will be stored in the main supervisor's office, room 3-6, level 2 at the Department of Speech-Language Pathology and Audiology at the University of Pretoria.

I have provided you with a copy of my dissertation proposal which includes copies of the procedures, information, and consent forms to be used in the research process.

Upon completion of this study, I undertake to provide the Department of Speech-Language Pathology and Audiology with a bound copy of the full research report. If you require any further information, please do not hesitate to contact me by email: u17064041@tuks.co.za.

Thank you for your time and consideration in this matter.

Yours sincerely,

Michèle Schoeman
Student

Prof. M. Soer
Supervisor

Prof. L. Pottas
Supervisor

Mrs. K.C. de Sousa
Supervisor

© University of Pretoria

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Office of the Registrar

2021-10-14 Ms M Schoeman

Department of Speech-Language Pathology and Audiology

Faculty of Humanities

UNIVERSITY OF PRETORIA

Email: u17064041@tuks.co.za

Dear Ms Schoeman

APPROVAL OF RESEARCH STUDY

The UP Survey Coordinating Committee has granted approval for the research study titled “Speech recognition in noise and temporal resolution abilities of formally trained musician”.

The proposed research study has to strictly adhere to the associated study protocol, as well as the UP Survey Policy and the Ethics Committee of the Faculty of Humanities instructions.

Please liaise with the Market Research Office in the Department of Institutional Planning (carlien.nell@up.ac.za) to officially register the study and to finalise the survey regulations, procedures and the fieldwork dates. In order to register the study, the Market Research Office has to receive the formal ethical approval letter from the Faculty of Humanities.

A final electronic copy of the research outcomes must be submitted to the Survey Coordinating Committee as soon as possible after the completion of the study.

Kind regards

Prof CMA Nicholson REGISTRAR CHAIRPERSON: SURVEY COORDINATING COMMITTEE

Rectorate, Room 4 -23, 4th floor, Administration Building, Hatfield Campus
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel : +27 (0)12 420 4236
Fax : +27 (0)12 420 5849
Email : regis @up.ac.za
www.up.ac.za

Kantoor van die Registrateur
Ofisi ya Mmušakarolo

© University of Pretoria

Appendix C: Letter to the Head of the Music Department

August 2021

Prof A Johnson
Head of Music Department

Dear Professor Johnson

REQUEST FOR PERMISSION TO CONDUCT RESEARCH

My name is Michèle Schoeman, and I am a registered student for a Masters degree in Audiology at the University of Pretoria. In order to complete my degree, I am required to conduct a research project. The research I wish to conduct involves the **evaluation and comparison of speech recognition and temporal resolution abilities in formally trained musicians with normal audiometric results**. This project will be conducted under the supervision of Prof. L. Pottas, Prof. M. Soer and Mrs. K. de Sousa. I hereby seek your consent to invite the students from the Music Department to participate in my research study. Should you provide me with permission to invite these students to participate, their participation would be entirely voluntary, and testing will not exceed 60 minutes.

Research background: Temporal processing is essential for the perception of verbal and non-verbal stimuli and can be defined as the shortest time necessary for a person to distinguish between two sounds. This ability plays an essential role in speech understanding, as it enables an individual to decode complex acoustic signals in the presence of competing background noise. Research has been suggesting that music can influence the central auditory pathway and improve speech recognition in noise. Some studies indicate that musicians outperform non-musicians with regard to their ability to recognise speech in noise. However, other studies have concluded that this musician advantage may only be evident in complex auditory tasks and that better speech recognition abilities may be due to working memory capacity, cognitive abilities, or other psychoacoustic tasks rather than musical experience. Consequently, studies have presented contradictory results, and the results remain unclear whether musicians have better speech recognition in noise compared to non-musicians. If musical expertise is beneficial for the recognition of speech in noise, music can be used to improve rehabilitation for individuals with hearing and language-related disorders. The aim of this study is to compare the temporal resolution and speech recognition abilities in different listening conditions in a sample of formally trained musicians compared to non-musicians.

Study participants: The participants will be required to present with clinically normal hearing sensitivity. One group, namely the musicians (aged 18-30 years) are required to have at least ten years of musical experience and practising consistently at least three times a week over the last three years before this study. Another group, namely the non-musicians are required to have no more than three years of musical experience over lifetime.

Ethical considerations: Ethical approval will be obtained from the Departmental Research and Ethics Committee (RESCOM) of the Department of Speech-Language Pathology and Audiology, the Research Ethics Committee of the Faculty of Humanities, and the Survey Committee of the University of Pretoria. Informed consent will be obtained from the participants, and an alphanumeric code will be allocated to each participant during the research study so that their results can be reported confidential. Participants

© University of Pretoria

will be assured that participation is voluntary and that they will be allowed to withdraw at any moment without any negative consequences.

Procedures to be followed:

- Following the informed consent, a questionnaire will be provided. The questionnaire will involve questions about the participants' medical and noise exposure history. The purpose of these questions is to exclude participants who do not adhere to the selection criteria of the study.
- A set of audiological tests will be conducted at the Music Department to determine the participants' outer, middle, and inner ear function. The participant will be required to sit still during objective tests or wear headphones and press a button to respond to sound.
- The South African English Digits-in-Noise test will then be conducted. Headphones will be placed on the participants' ears and he/she will hear a series of digit-triplets. The participant will be required to respond by typing on the smartphone what he/she have heard.
- The Gaps-in-Noise test will be conducted at the Department of Speech-Language Pathology and Audiology. Headphones will be placed on the participants' ears and he/she will hear a noise with varied and randomised gaps in between. The participant will be required to report when he/she have heard the gaps.

Risks and benefits: There are no foreseeable physical discomfort or risk involved with regards to the testing procedures. Should participants feel uncomfortable, fatigue, or emotionally distressed, he/she may withdraw from the study without any negative consequences. There are, however, minimal risks involved due to COVID-19 and all COVID-19 protocols will be followed. Participants will not benefit directly from this study; however, participants will receive a free hearing test. Should participants present with any auditory difficulties or hearing loss, he/she will be referred to the Department of Speech-Language Pathology and Audiology at the University of Pretoria where further testing and early intervention and management can take place.

Data storage: Data from this research project will be digitally stored for a minimum of fifteen (15) years after completion of the original project on the University's institutional Research Data Management system, where it will be secured and conserved through the University's research data management archive system and made available through the University of Pretoria's Research Data Management Repository, if applicable. A hard copy will be stored in the main supervisor's office, room 3-6, level 2 at the Department of Speech-Language Pathology and Audiology at the University of Pretoria.

I have provided you with a copy of my dissertation proposal which includes copies of the procedures, information, and consent forms to be used in the research process.

Upon completion of this study, I undertake to provide the Department of Speech-Language Pathology and Audiology with a bound copy of the full research report. If you require any further information, please do not hesitate to contact me by email: u17064041@tuks.co.za.

Thank you for your time and consideration in this matter.

Yours sincerely,

Michèle Schoeman
Student

Prof. M. Soer
Supervisor

Prof. L. Pottas
Supervisor

Mrs. K.C. de Sousa
Supervisor

© University of Pretoria

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Office of the Head:School of the Arts

October 2021

Ms MN Schoeman

Department of Speech-Language Pathology and Audiology

Dear Ms Schoeman

PERMISSION TO CONDUCT RESEARCH

This letter confirms the permission given to Michèle Schoeman to invite and recruit the students from the Music Department at the University of Pretoria to participate in the research study titled “Speech recognition in noise and temporal resolution abilities of formally trained musicians”.

I hereby confirm that I have read and understood the information letter given to me.

Kind regards

Alexander Johnson
Professor and Head: School of the Arts

Chair: Music

© University of Pretoria

Appendix D: Informed consent

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Humanities 100.
1919 - 2019
Department of Speech-Language Pathology & Audiology

SPEECH RECOGNITION IN NOISE AND TEMPORAL RESOLUTION ABILITIES IN FORMALLY TRAINED MUSICIANS

Dear Participant

You are invited to participate in a research study. This document will provide you with information about the research study and to help you to decide if you would like to participate. Before you sign the informed consent, it is important that you fully understand what is involved. If you have any questions or have any uncertainty about the research procedures, please do not hesitate to ask the researchers.

PURPOSE OF THE RESEARCH

This study aims to compare speech recognition in noise and temporal resolution abilities in individuals aged between 18 and 30 years with clinically normal hearing sensitivity. Musicians are required to have musical experience at least ten years of musical experience, practising consistently at least three times a week over the last three years before this study. Non-musicians are required to have no more than three years of total musical experience over lifetime. By conducting this study, results can be used to improve rehabilitation for individuals with hearing and language related disorders, or perhaps enhance the importance of hearing protection against high levels of music exposure.

EXPLANATION OF PROCEDURES TO BE FOLLOWED

- The researcher will provide a self-administered questionnaire and assist you if there is any uncertainty about the questions. The questionnaire will involve questions about your medical and noise exposure history. The purpose of these questions is to exclude participants who do not adhere to the selection criteria of the study.
- The researcher will conduct a set of audiological tests to determine your outer, middle, and inner ear function. You will be required to sit still during objective tests or wear headphones and press a button to respond to sound.
- The South African English Digits-in-Noise test will then be conducted. Headphones will be placed on your ears and you will hear a series of digit-triplets. You will be required to respond by typing on the smartphone what you have heard.
- The Gaps-in-Noise test will be conducted at the Department of Speech-Language Pathology and Audiology. Headphones will be placed on your ears and you will hear a noise with varied and randomised gaps in between. You will be required to report when you have heard the gaps.
- The entire evaluation will take approximately 60 minutes to complete.

RISK AND DISCOMFORT INVOLVED

There is no foreseeable physical discomfort or risk involved with regards to the testing procedures. There are, however, minimum risks due to COVID-19 and COVID-19 protocols will be followed. Should you feel uncomfortable, fatigue or emotionally distressed, please inform the researcher.

POSSIBLE BENEFITS INVOLVED

You may not benefit directly from this research study. However, the results of this study may assist in the making of rehabilitation programmes for individuals with hearing and language related disorders and/or enhance the importance of hearing protection against harmful music exposure. Furthermore,

© University of Pretoria

you will have the opportunity to receive a free hearing test and the results will be made available to you. Should you present with any auditory difficulties or hearing loss, you will be referred to the Department of Speech-Language Pathology and Audiology at the University of Pretoria, or another practice of your choosing, where further testing and early intervention and management can take place.

ETHICS APPROVAL
A written ethical approval for this study has been granted by the Departmental Research and Ethics Committee of the Department of Speech-Language Pathology and Audiology, the RESCOM faculty of Humanities, as well as the Survey Committee of the University of Pretoria. A copy of the ethical clearance letter may be obtained from the researcher should you wish to review it.

RIGHT TO REFUSE OR WITHDRAW
You have the right to refuse or withdraw at any time or stage during this research study without any negative consequences. Participation in this research study is voluntary. Should you withdraw participation from this study, all data obtained from you will be destroyed and will not be used in the study.

CONFIDENTIALITY
An alphanumeric code will be allocated to each participant during the research study so that their results can be reported confidential. The participant's personal identity and case history information will only be known to the researcher.

DATA STORAGE
The University of Pretoria's research data management policy states that research data sets are required to be stored for a minimum of ten (10) years after completion of the original project. Data from this research project will be stored digitally on the University's institutional Research Data Management system, where it will be secured and conserved through the University's research data management archive system and made available through the University of Pretoria's Research Data Management Repository, if applicable. A hard copy will be stored in the supervisor's office at the Department of Speech-Language Pathology and Audiology at the University of Pretoria.

COVID-19 SAFETY PROTOCOL
In line with the COVID-19 safety protocol you will be given a symptom screening checklist, and your temperature will be measured prior to and on the day of testing. All COVID-19 safety protocol guidelines should be followed at all times.

Should you have any questions concerning this research study or request more information, you may contact me by 083 663 3351 or email u17064041@tuks.co.za, or my supervisors Prof. L. Pottas by dialling 012 420 2815 or e-mail: lidia.pottas@up.ac.za, Prof. M. Soer at 012 420 2304 or maggi.soer@up.ac.za, or Mrs. K.C. de Sousa at 082 556 5431 or karina.swanepoel@up.ac.za.

Please indicate your consent by signing on this copy of the informed consent letter.
Herewith I, _____ give consent to participate in the research study.
I have read the informed consent letter and understand what is requested.

_____ _____
Participant's signature Date

_____
Michèle Schoeman
Student

_____ _____ _____
Prof. M. Soer Prof. L. Pottas Mrs. K.C. de Sousa
Supervisor Supervisor Supervisor

© University of Pretoria

Appendix E: Referral letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Humanities 100.
1919 - 2019
Department of Speech-Language Pathology & Audiology

REFERRAL LETTER

Dear _____

This letter confirms that your hearing was screened on _____at the University of Pretoria. Results indicated that further diagnostic assessment is necessary for the following reason(s) _____
_____.

Please see your nearest audiologist of visit the Department of Speech-Language Pathology and Audiology at the University of Pretoria for a full diagnostic evaluation.

Please contact the Department of Speech-Language Pathology and Audiology at 012 420 2816 should you require any additional information.

Yours sincerely,

_____
Michèle Schoeman
Student

_____	_____	_____
Prof. M. Soer	Prof. L. Pottas	Mrs. K.C. de Sousa
Supervisor	Supervisor	Supervisor

© University of Pretoria

Appendix F: Plagiarism declaration

UNIVERSITY OF PRETORIA
FACULTY OF HUMANITIES
DEPARTMENT SPEECH-LANGUAGE PATHOLOGY AND AUDIOLOGY

Full name: Michèle Nicole Schoeman

Student Number: 17064041

Degree: MA Audiology

I declare that this research report is my own original work. Where secondary material is used, this has been carefully acknowledged and referenced in accordance with university requirements.

I understand what plagiarism is and are aware of the University of Pretoria's policy in this regard.

_____ 2021/02/25
Signature Date

© University of Pretoria

Appendix G: Permission letter to the Music Department

October 2021

Prof C Panebianco

Music Department

Dear Professor Panebianco

REQUEST TO INVITE STUDENTS TO PARTICIPATE IN A RESEARCH STUDY

My name is Michèle Schoeman, and I am a registered student for a Masters degree in Audiology at the University of Pretoria. In order to complete my degree, I am required to conduct a research project. The research I wish to conduct involves the **evaluation and comparison of speech recognition and temporal resolution abilities in formally trained musicians**. This project will be conducted under the supervision of Prof. L. Pottas, Prof. M. Soer and Mrs. K. de Sousa. I hereby request your help to invite (e.g. via class introductions) the students from the Music Department to participate in my research study. Should you agree to invite these students to participate, their participation would be entirely voluntary, and testing will not exceed 60 minutes.

Research background: Temporal processing is essential for the perception of verbal and non-verbal stimuli and can be defined as the shortest time necessary for a person to distinguish between two sounds. This ability plays an essential role in speech understanding, as it enables an individual to decode complex acoustic signals in the presence of competing background noise. Research has been suggesting that music can influence the central auditory pathway and improve speech recognition in noise. Some studies indicate that musicians outperform non-musicians with regard to their ability to recognise speech in noise. However, other studies have concluded that this musician advantage may only be evident in complex auditory tasks and that better speech recognition abilities may be due to working memory capacity, cognitive abilities, or other psychoacoustic tasks rather than musical experience. Consequently, studies have presented contradictory results, and the results remain unclear whether musicians have better speech recognition in noise compared to non-musicians. If musical expertise is beneficial for the recognition of speech in noise, music can be used to improve rehabilitation for individuals with hearing and language-related disorders. The aim of this study is to compare the temporal resolution and speech recognition abilities in

© University of Pretoria

different listening conditions in a sample of formally trained musicians compared to non-musicians.

Study participants: The participants will be required to present with clinically normal hearing sensitivity. One group, namely the musicians (aged 18-30 years) are required to have at least ten years of musical experience and practising consistently at least three times a week over the last three years before this study. Another group, namely the non-musicians are required to have no more than three years of musical experience over lifetime.

Ethical considerations: Ethical approval will be obtained from the Departmental Research and Ethics Committee (RESCOM) of the Department of Speech-Language Pathology and Audiology, the Research Ethics Committee of the Faculty of Humanities, the Survey Committee of the University of Pretoria, as well as the Head of the Music Department. Informed consent will be obtained from the participants, and an alphanumeric code will be allocated to each participant during the research study so that their results can be reported confidential. Participants will be assured that participation is voluntary and that they will be allowed to withdraw at any moment without any negative consequences

Procedures to be followed:

- Following the informed consent, a questionnaire will be provided. The questionnaire will involve questions about the participants' medical and noise exposure history. The purpose of these questions is to exclude participants who do not adhere to the selection criteria of the study.
- A set of audiological tests will be conducted at the Music Department to determine the participants' outer, middle, and inner ear function. The participant will be required to sit still during objective tests or wear headphones and press a button to respond to sound.
- The South African English Digits-in-Noise test will then be conducted. Headphones will be placed on the participants' ears and he/she will hear a series of digit-triplets. The participant will be required to respond by typing on the smartphone what he/she have heard.
- The Gaps-in-Noise test will be conducted at the Department of Speech-Language Pathology and Audiology. Headphones will be placed on the participants' ears and he/she will hear a noise with varied and randomised gaps in between. The participant will be required to report when he/she have heard the gaps.

Risks and benefits: There are no foreseeable physical discomfort or risk involved with regards to the testing procedures. Should participants feel uncomfortable, fatigue, or emotionally distressed, he/she may withdraw from the study without any negative consequences. There are, however, minimal risks involved due to COVID-19 and all COVID-19 protocols will be followed. Participants will not benefit directly from this study; however, participants will receive a free hearing test. Should participants present with any auditory difficulties or hearing loss, he/she will be referred to the Department of Speech-Language Pathology and Audiology at the University of Pretoria where further testing, early intervention, management, and support can take place.

Data storage: Data from this research project will be digitally stored for a minimum of fifteen (15) years after completion of the original project on the University's institutional Research Data Management system, where it will be secured and conserved through the University's research data management archive system and made available through the University of Pretoria's Research Data Management Repository, if applicable. A hard copy will be safely

© University of Pretoria

stored in the main supervisor's office, room 3-6, level 2 at the Department of Speech-Language Pathology and Audiology at the University of Pretoria.

I have provided you with a copy of my dissertation proposal which includes copies of the procedures, information, and consent forms to be used in the research process.

Upon completion of this study, I undertake to provide the Department of Speech-Language Pathology and Audiology with a bound copy of the full research report. If you require any further information, please do not hesitate to contact me by email: u17064041@tuks.co.za.

Thank you for your time and consideration in this matter.

Yours sincerely,

Michèle Schoeman

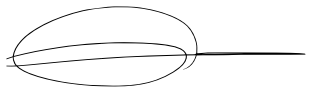
Student

Prof. M. Soer
Supervisor

Prof. L. Pottas
Supervisor

Mrs. K.C. de Sousa
Supervisor

I, _____Clorina Panebianco_____ hereby confirm that I have read and understood the above information. I will provide my assistance to invite the students from the Music Department at the University of Pretoria to participate in this research study.



Signature

__October 2021___

Date

© University of Pretoria

Appendix H: Questionnaire

1. What is your age?
2. What is your gender?
    a. Male
    b. Female
    c. Non-binary
3. What is your main instrument? If you are mainly a vocalist, please write the instrument you play in addition to singing.
4. If you play any instrument(s) additional to your main instrument, please indicate the type of instrument(s).
5. Please indicate the duration of experience you have with your main instrument.
6. Would you say that you have played your instrument consistently for at least 3 years?
7. On average, how many hours per day are you exposed to your instrument?
8. Do you often play your instrument within a band or orchestra, or do you mostly play your instrument in isolation?
9. Please indicate all the relevant option(s)
    a. Family history of hearing loss due to reasons other than noise/age
    b. History of middle ear infection starting in childhood
    c. History of middle ear infection starting later in life
    d. Traumatic head injuries where the ears were damaged
10. Did you have any ear surgeries? If so, please specify the type of surgery.
11. Do you use any chronic medications? If so, please specify what medications.
12. Have you ever had your hearing tested before?
    a. No, I have not
    b. Yes, less than a year ago
    c. Yes, between 2 and 5 years ago
    d. Yes, more than 5 years ago
    e. Yes, as a new-born/child younger than 3 years old
13. Have you experienced any of the following types of hearing problems
    a. Hearing loss (temporary)
    b. Hearing loss (permanent)
    c. Unilateral hearing loss (one ear only)
    d. Middle ear infections (at your current age)
14. Do you ever experience tinnitus (roaring, buzzing, ringing sound)
    a. Never
    b. Yes, all the time
    c. Yes, often but not always
    d. Yes, sometimes, but not regularly
15. When do you experience tinnitus mostly?
    a. After exposure to loud noise/sounds
    b. After playing my instrument
    c. After an individual rehearsal session with a group of musicians
    d. Nothing really triggers it, it occurs randomly
16. Do you experience hyperacousis?
    a. Yes
    b. No
    c. Unsure

© University of Pretoria

17. Do you currently or have previously worked in a noisy environment aside from your musical activities?
    a. No
    b. Yes, more than 3 days a week
    c. Yes, less than 3 days a week
    d. Yes, more than a year ago
18. Did you wear hearing protection during these noise exposures?
    a. Always
    b. Most of the time
    c. Sometimes
    d. Never
19. Do you use any form of hearing protection while
    a. Practising alone
    b. At rehearsals with other players
    c. Other people's performances
20. The type of hearing protection that I use
    a. Own hearing protection
    b. Single use soft ear plugs
    c. Reusable soft earplugs
    d. Custom made ear plugs
21. Please enter your number that the researcher gave you

© University of Pretoria

Appendix I: Data collection sheet

Data collection sheet

SPEECH RECOGNITION IN NOISE AND TEMPORAL RESOLUTION ABILITIES IN FORMALLY TRAINED MUSICIANS COMPARED TO NON-MUSICIANS

Date		Age	
Participant alphanumeric code		Male / female	
Musician (M) / Non-musician (NM)		Music instrument	

OTOSCOPIC EXAMINATION
Right ear _____Left ear _____

IMMITTANCE TESTING

Right	Type		Left	Type	
	Pressure			Pressure	
	Compliance			Compliance	
	Volume			Volume	
	1000 Hz Ipsi			1000 Hz Ipsi	

PURE TONE AUDIOMETRY
Right ear

250	**500**	**1000**	**2000**	**4000**	**8000**	**10 000**	**12 000**	**16 000**
PTA								

Left ear

250	**500**	**1000**	**2000**	**4000**	**8000**	**10 000**	**12 000**	**16 000**
PTA								

DIN TESTING

In phase condition		
Out of phase condition		

GIN TESTING
See lists attached

© University of Pretoria

Appendix H: Proof of submission of article

Journal of Speech, Language, and Hearing Research

Speech recognition in noise and temporal resolution: A comparison between formally trained musicians and non-musicians

--Manuscript Draft--

Manuscript Number:	JSLHR-22-00616
Full Title:	Speech recognition in noise and temporal resolution: A comparison between formally trained musicians and non-musicians
Article Type:	Research Article
Section/Category:	Hearing
Corresponding Author:	Michele Nicole Schoeman, BA Audiology UP: University of Pretoria Witbank, Mpumalanga SOUTH AFRICA
Other Authors:	Lidia Pottas
	Maggi Soer
	Karina C. De Sousa
	Marien A. Graham
Funding Information:	
Keywords:	musicians; temporal resolution; speech recognition in noise
Manuscript Classifications:	Audiology; Central auditory processing; Hearing; Noise; Psychoacoustics; Speech recognition
Abstract:	Purpose: This study compared the speech recognition in noise and temporal resolution abilities in formally trained musicians with normal hearing to a similar group of nonmusicians. Method: A quantitative cross-sectional comparative group research design was used in this study. Each participant's conventional and extended high frequency (EHF) pure tone thresholds, homophasic and antiphasic speech recognition in noise thresholds (SRT), and temporal resolution were tested. A binaural intelligibility-level difference was calculated using the values obtained in the homophasic and antiphasic listening conditions. Forty formally trained musicians and 40 age and gender-matched nonmusicians participated. Selection procedures included otoscopy, tympanometry, and pure tone audiometry. All participants presented with PTA thresholds at 0.5 to 4 kHz < 15 dB HL. Results: No significant group differences were obtained in EHF, DIN and BILD, or the GIN test. Although the musicians achieved slightly better results in the speech recognition in noise and temporal resolution tests, the differences were not significant ($p > .05$). Conclusions: Musicians performed slightly better, although not significantly different than non-musicians in the GIN testing and the DIN test. No statistically significant difference between the two groups in BILD was observed.

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

© University of Pretoria