

EVALUATING THE PERFORMANCE OF AN  
ELECTRONIC HEARING PROTECTION DEVICE WITH  
SELECTIVE NOISE ATTENUATION.

BY

MUHAMMAD MAWADDI BIN MOHAMMAD ABDUL  
QAHAR

A thesis submitted in fulfilment of the requirement for the  
degree of Master of Medical Sciences (Audiology Science)

Kulliyyah of Medicine  
International Islamic University Malaysia

JANUARY 2022

## ABSTRACT

**Objective:** This study evaluated the performance of the recently developed IIUM e-HPD prototype in noise attenuation and speech intelligibility scores. **Method:** This study used a quasi-experimental study design. Firstly, the applications of digital signal algorithms and their effect on speech intelligibility for in-ear type e-HPD were discovered through a systematic review. First, six databases were searched using the following key concept of terms: “hearing protection device” and “algorithm”, and “speech intelligibility”. Next, a Modified Acoustic Test Fixture (MATF) test was conducted to measure and calculate the insertion loss (dB) at different ear conditions (Open ear, Occluded ear, Record and playback algorithm and NLMS filter) at 500 and 2000 Hz at 80 and 90 dB SPL. Meanwhile, the Modified Hearing in Noise Test (MHINT) were conducted to measure the speech recognition threshold in noise (dB SNR) using The Malay Hearing in Noise Test speech material. The study compared the insertion loss (dB) between the ear conditions at at 500 and 2000 Hz at 80 and 90 dB SPL . The speech recognition threshold in noise was compared between the all four experimental conditions. **Results:** The systematic review revealed nine references testing the speech intelligibility of the in-ear type of e-HPD. These findings were identified under three themes: Population, algorithm and speech intelligibility tests. The insertion loss calculated showed the highest insertion loss achieved by the occluded ear at 500 and 2000 Hz. Negative insertion loss observed at 2000 Hz for the open ear, the occluded ear and the Normalised Least-Mean-Square (NLMS) filter with the NLMS filter were the lowest insertion loss calculated. RM-ANOVA was performed on the insertion loss (dB) from MATF test results it showed a significant difference ( $p < .05$ ) between the main effect and pairwise comparison of the ear conditions, noise level, and frequencies of interest. Polynomial contrast showed significant linear, quadratic and cubic components ( $P > 0.10$ ) except at the interaction between condition, noise level and frequencies of interest. A one way RM-ANOVA of the MHINT on the ear conditions indicated a significant main ( $p < .05$ ) while the pairwise comparison of the ear conditions showed a significant difference between the open ear and NLMS filter only. **Conclusion:** In summary, the developed e-HPD prototype was able to attenuate noise although not as comparable to an occluded ear while preserving the speech intelligibility in noise compared with open ear.

## خلاصة البحث

إن الهدف من هذه الدراسة هي تقييم أداء النموذج الأولي IIUM e-HPD المطور مؤخرا في توهين الضوضاء ودرجات وضوح الكلام. وقد استخدمت الدراسة تصميم شبه تجريبية منهجا للبحث. أولا، تم اكتشاف تطبيقات خوارزميات الإشارة الرقمية وتأثيرها على وضوح الكلام لنوع e-HPD داخل الأذن من خلال مراجعة منهجية. تم البحث في ست قواعد بيانات باستخدام المصطلحات الرئيسية التالية: "جهاز حماية السمع" و"الخوارزمية"، و"وضوح الكلام". ثم تم اجراء اختبار تركيبات الاختبار الصوتية المعدلة (MATF) لقياس وحساب فقدان الإدخال (dB) في ظروف الأذن المختلفة (الأذن المفتوحة، والأذن المسدودة، وخوارزمية التسجيل والتشغيل، ومرشح NLMS) عند 500 و 2000 هرتز عند 80 و 90 dB SPL. وفي نفس الوقت، تم اختبار السمع المعدل في الضوضاء (MHINT) لقياس عتبة التعرف على الكلام في الضوضاء (dB SNR) باستخدام مادة الكلام الملايو للسمع في اختبار الضوضاء. قارنت الدراسة فقدان الإدخال (dB) بين ظروف الأذن عند 500 و 2000 هرتز عند 80 و 90 dB SPL. وتمت مقارنة عتبة التعرف على الكلام في الضوضاء بين جميع الظروف التجريبية الأربعة. ومن أهم نتائجها كشفت المراجعة المنهجية عن تسعة مراجع تختبر وضوح الكلام لنوع داخل الأذن من e-HPD. وحددت هذه النتائج في ثلاثة محاور: السكان، والخوارزمية، واختبارات وضوح الكلام. أظهر فقدان الإدخال المحسوب أعلى فقدان الإدخال حققه الأذن المسدودة عند 500 و 2000 هرتز. كان فقدان الإدخال السلبي الذي لوحظ عند 2000 هرتز للأذن المفتوحة، والأذن المسدودة، ومرشح المربع الأدنى المعياري (NLMS) مع مرشح NLMS هو أقل فقدان الإدخال المحسوب. تم

أجراء RM-ANOVA على فقدان الإدخال ( $P < 0.05$ ) من نتائج اختبار MATF حيث أظهر  
فرقا كبيرا بين التأثير الرئيسي والمقارنة الزوجية لظروف الأذن، ومستوى الضوضاء، والترددات ذات الأهمية.  
أظهر التباين متعدد الحدود مكونات خطية، وتربيعية، ومكعبية معنوية ( $P > 0.10$ ) باستثناء التفاعل بين  
الطرف، ومستوى الضوضاء، والترددات ذات الأهمية. أشارت طريقة واحدة RM-ANOVA  
من MHINT لظروف الأذن إلى وجود رئيسي مهم ( $P < 0.05$ ) بينما أظهرت المقارنة الزوجية لظروف  
الأذن فرقا كبيرا بين الأذن المفتوحة ومرشح NLMS فقط. الخلاصة: باختصار، كان النموذج الأولي  
e-HPD المطور قادرا على تخفيف الضوضاء، وعلى الرغم من أنه لا يمكن مقارنته بالأذن المسدودة  
مع الحفاظ على وضوح الكلام في الضوضاء مقارنة بالأذن المفتوحة .

## APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of of Medical Science (Audiology Sciences).

.....  
Ailin Razali  
Supervisor

.....  
Saiful Adli Jamaluddin  
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Medical Sciences (Audiology Sciences).

.....  
Dinsuhaimi Sidek  
Internal Examiner

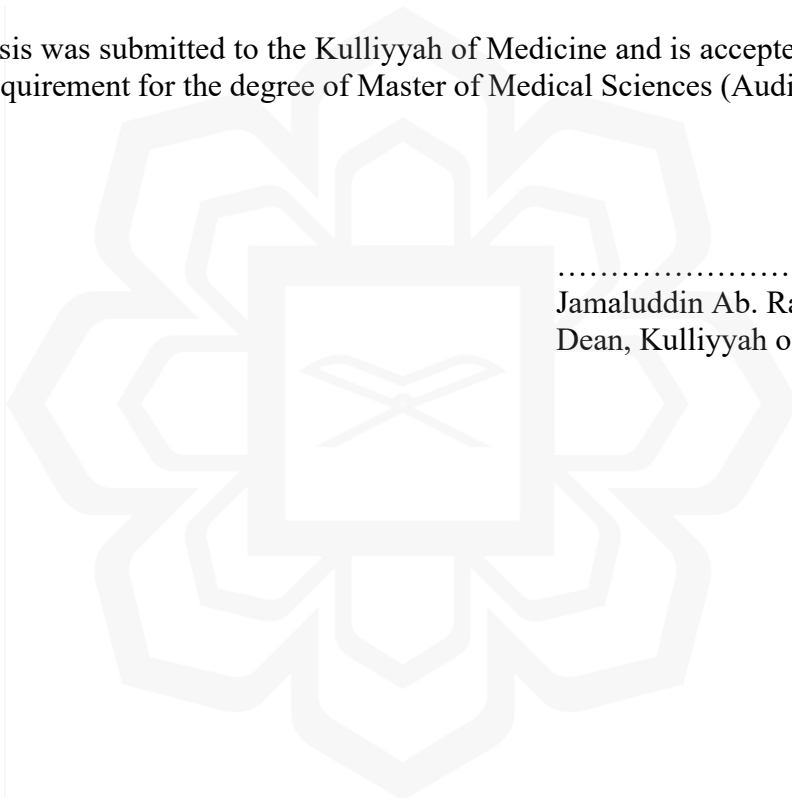
.....  
Mohd Normani Zakaria  
External Examiner

This thesis was submitted to the Department of Otorhinolaryngology, Head and Neck Surgery (ORL-HNS) and is accepted as a fulfilment of the requirement for the degree of Master of of Medical Sciences (Audiology Sciences).

.....  
Wan Ishlah Leman  
Head, Department of  
Otorhinolaryngology, Head and  
Neck Surgery (ORL-HNS)

This thesis was submitted to the Kulliyyah of Medicine and is accepted as a fulfilment of the requirement for the degree of Master of Medical Sciences (Audiology Sciences).

.....  
Jamaluddin Ab. Rahman  
Dean, Kulliyyah of Medicine



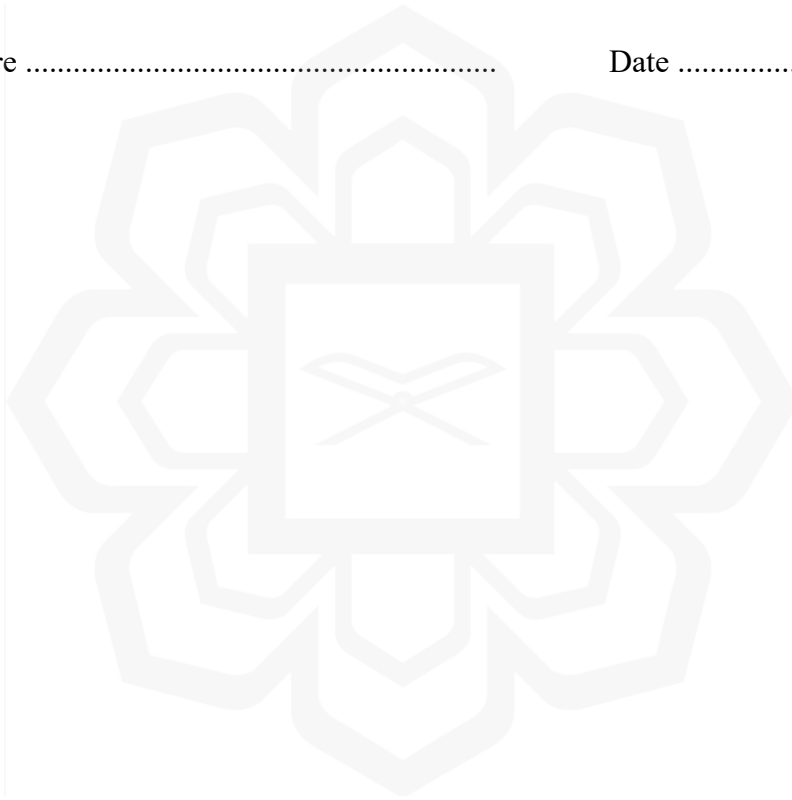
## DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Muhammad Mawaddi Bin Mohammad Abdul Qahar

Signature .....

Date .....



**INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA  
DECLARATION OF COPYRIGHT AND AFFIRMATION OF  
FAIR USE OF UNPUBLISHED RESEARCH**

**EVALUATING THE PERFORMANCE OF AN ELECTRONIC  
HEARING PROTECTION DEVICE WITH SELECTIVE NOISE  
ATTENUATION.**

I declare that the copyright holders of this dissertation are jointly owned by the student and IIUM.

Copyright © 2021 Muhammad Mawaddi Bin Mohammad Abdul Qahar and International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.
3. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Muhammad Mawaddi Bin Mohammad Abdul Qahar

.....  
Signature

.....  
Date



## ACKNOWLEDGEMENTS

Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience.

I wish to express my appreciation and thanks to those who provided their time, effort and support for this project. To the members of my dissertation committee, thank you for sticking with me.

I am most indebted to Assoc. Prof. Dr. Ailin Razali for her continuous support, encouragement and leadership, and for that, I will be forever grateful. I am also grateful to Asst. Prof. Dr. Saiful Adlin Bin Jamaluddin for whose support and cooperation contributed to the outcome of this work. Thank you also to Dr. Tang Howe Hing for providing the support with developing the prototype used in this study. I would also express my heartfelt gratitude to Brother Mohd Ariff Hazami Elliazir and Namirah Mohamed for your continuous support and motivation during this study. Finally, Thank you to Aina Mastura and Siti Syahzanan for helping me during the progress of this study.

Once again, we glorify Allah for His endless mercy on us one of which is enabling us to successfully round off the efforts of writing this thesis. Alhamdulillah.

# TABLE OF CONTENTS

Abstract .....	ii
Approval page .....	v
Declaration .....	vii
Acknowledgements .....	ix
Table of contents .....	x
List of Tables .....	xiv
List of Figures .....	xv
List of Abbreviation .....	xvii
Glossary .....	xix
<b>CHAPTER ONE: INTRODUCTION .....</b>	<b>1</b>
1.1 Background of The Study .....	2
1.2 Statement of The Problem .....	4
1.3 Purpose of The Study .....	4
1.4 Research Objectives .....	5
1.5 Research Questions.....	6
1.6 Research Hypothesis.....	7
1.7 Significance of The Study .....	7
<b>CHAPTER TWO: LITERATURE REVIEW.....</b>	<b>8</b>
<b>PART ONE: THEORETICAL REVIEW.....</b>	<b>8</b>
2.1 Introduction .....	8
2.2 Occupational Noise-Induced Hearing Loss .....	8
2.3 Anatomy and Physiology of The Human Ear.....	10
2.4 Patophysiology of Noise-Induced Hearing Loss .....	10
2.5 Hearing Protection Device.....	12
2.5.1 Mode of Protection.....	14
2.5.2 Technology of e-HPD .....	17
2.6 Development of e-HPD Prototype.....	18
2.7 Attenuation of a Hearing Protection Device.....	19
2.7.1 Insertion Loss .....	19
2.8 Speech Intelligibility.....	21

2.9 Chapter Summary .....	22
---------------------------	----

**CHAPTER THREE: METHODOLOGY.....23**

3.1 Introduction .....	23
3.2 Exploration of The Literature on The Applications of Digital Signal Processing Algorithms and Their Effects on Speech Intelligibility for In-Ear Type of e-HPD .....	24
3.2.1 Instrumentation .....	24
3.2.2 Procedure .....	25
3.2.2.1 Selection Criteria .....	25
3.2.2.2 Identification of Research Evidence.....	26
3.2.2.3 Data Extraction .....	27
3.2.2.4 Quality Assessment .....	28
3.2.2.5 Data Synthesis .....	28
3.3 Measurement and Calculation of The Insertion Loss (dB) and The Measurement of Speech Recognition Threshold in Noise (dB SNR) for The In-Ear e-HPD Prototype Developed by IIUM.....	28
3.3.1 Measurement of Output (dB SPL) for The in-ear e-HPD Prototype Developed by IIUM .....	28
3.3.1.1 Instrument.....	29
3.3.1.2 Procedure .....	33
3.3.2 Calculation of The Insertion Loss (dB).....	39
3.3.2.1 Instrument.....	39
3.3.2.2 Procedure .....	39
3.3.3 Measurement of The Speech Recognition Threshold in Noise (dB SNR) for the in-ear e-HPD Prototype Developed by IIUM ..	41
3.3.3.1 Instrument.....	41
3.3.3.2 Procedure .....	42
3.4 Comparison of The Insertion Loss (dB) for The In-Ear Type of e-HPD Developed by IIUM Between Four Ear Conditions at Two Levels of Noise and Two Frequencies of Interests .....	47
3.4.1 The Effects of Ear Conditions on the Insertion Loss at 80 and 90 dB SPL Noise and 500 and 2000 Hz .....	47
3.5 Comparisons of The Speech Recognitions Thresholds in Noise (dB SNR) of Participants Between The In-Ear Type of e-HPD Developed by IIUM and The Open Ear, The Occluded Ear and The Record and Playback Algorithm.....	48
3.5.1 . Instrument .....	48
3.5.1.1 IBM SPSS Statistics 20 Software.....	48
3.5.2 Statistical Analysis Plan.....	48
3.6 Approval and Ethical Consideration.....	49

<b>CHAPTER FOUR: RESULTS .....</b>	<b>50</b>
4.1 Introduction .....	50
4.2 Exploration of The Literature on The Applications of Digital Signal Processing Algorithms and Their Effects on Speech Intelligibility for In-Ear Type of e-HPD .....	51
4.2.1 Data Extraction and Synthesis .....	51
4.2.2 Quality Appraisal .....	53
4.2.3 Study characteristics .....	55
4.3 Measurement and Calculation of The Insertion Loss (dB) and The Measurement of Speech Recognition Threshold in Noise (dB SNR) for The In-Ear e-HPD Prototype Developed by IIUM.....	59
4.3.1 Measurement of Output (dB SPL) for The in-ear e-HPD Prototype Developed by IIUM .....	59
4.3.2 Descriptive Statistics.....	62
4.4 Insertion Loss (dB) Calculation and Comparison Between The In-Ear Type of e-HPD Developed with The Ear Conditions.....	63
4.4.1 Insertion Loss (dB) Calculation .....	63
4.4.2 The Effects of Ear Conditions on the Insertion Loss at 80 and 90 dB SPL Noise and 500 and 2000 Hz .....	66
4.5 Comparison of The Speech Recognition Threshold in Noise (dB SNR) Between The Developed e-HPD Prototype with NLMS Filter and Ear Condition.....	68
4.5.1 Speech Recognition Threshold in Noise (dB SNR) for The Developed e-HPD Prototype and Ear Conditions .....	68
4.5.2 The Effect of Ear Conditions on The Speech Recognition Threshold in Noise (dB SNR) .....	70
<b>CHAPTER FIVE: DISCUSSIONS .....</b>	<b>73</b>
5.1 Introduction .....	73
5.2 Exploration of The Literature on The Applications of Digital Signal Processing Algorithms and Their Effects on Speech Intelligibility for In-Ear Type of e-HPD .....	74
5.2.1 Key Themes .....	74
5.2.1.1 Sample variability .....	74
5.2.1.2 Speech Intelligibility.....	75
5.2.1.3 Noise Reduction Algorithms .....	76
5.3 Measurement and Calculation of The Insertion Loss (dB) and The Measurement of Speech Recognition Threshold in Noise (dB SNR) for The In-Ear E-HPD Prototype Developed by IIUM .....	76
5.4 Insertion Loss (dB) Calculation and Comparison Between The In-Ear Type of e-HPD Developed with The Ear Conditions.....	77
5.4.1 Analysis of The Main Effect.....	77

5.4.2 Polynomial Contrasts .....	78
5.4.3 Attenuation Performance at 500 Hz.....	78
5.4.4 Attenuation Performance at 2000 Hz.....	79
5.5 Comparison of The Speech Recognition Threshold in Noise (dB SNR) Between The Developed e-HPD Prototype With NLMS Filter With Ear Conditions .....	80
5.5.1 The Effect of Ear Conditions on The Speech Recognition Threshold in Noise (dB SNR) .....	82
5.5.1.1 Analysis of the Main Effect.....	82
<b>CHAPTER SIX: CONCLUSION .....</b>	<b>83</b>
6.1 Summary of Findings .....	83
6.2 Limitation .....	85
6.3 Direction for Future Research .....	86
6.4 Conclusion .....	86
<b>REFERENCES.....</b>	<b>87</b>
<b>APPENDIX L: MATHLAB CODING.....</b>	<b>xxii</b>

## LIST OF TABLES

Table 1	Variable Used for ATF test	36
Table 2	Variables Used for Hearing in Noise Test (HINT)	44
Table 3	Quality appraisal scores for the nine studies included in the review	54
Table 4	Characteristics of included studies (n=9)	56
Table 5	Means and Standard Deviation of Output level recorded (dBSPL) Across Four different conditions 2 Different Frequencies from 80 dBSPL Noise Stimulation	62
Table 6	Means and Standard Deviation of Output level recorded (dBSPL) Across Four different conditions 2 Different Frequencies from 90 dBSPL Noise Stimulation	63
Table 7	Means and Standard Deviation of Insertion Loss (dBIL) Across Four different conditions 2 Different Frequencies and level (dBSPL) of Noise Stimulation	64
Table 8	Repeated-Measures ANOVA Significant Main Effects Over Different Frequencies at Different Noise Levels	67
Table 9	ANOVA Tests of Within-Subject Contrasts to Show Quadratic Change Over Different Frequencies at Different Noise Levels	67
Table 10	Means and Standard Deviation of Signal to Noise Ratio (SNR) Across Four different conditions (N= 34)	69
Table 11	ANOVA Tests of Within-Subject Contrasts to Show Quadratic Change Over Different Frequencies at Different Noise Levels	71
Table 12	Pairwise Comparisons for Conditions Versus Target	72

## LIST OF FIGURES

Figure 1	Prototype Worn by a User	18
Figure 2	Interaction between principal components of the e-HPD prototype	29
Figure 3	Noise Reduction Process for e-HPD Prototype	30
Figure 4	Field Programmable Gate Array (FPGA) Platform	31
Figure 5	Experimental setup for Acoustic Test Fixture	32
Figure 6	Microphone placement on the head of the ATF	33
Figure 7	Four × Two × Two Three-Way Interaction Between The Dependent Variables	35
Figure 8	Spectral Analysis of 500 Hz Pink Noise Generated	38
Figure 9	Flowchart for ATF Testing	38
Figure 10	The Interaction of data from the Matlab into IBM SPSS Statistics Software	40
Figure 11	Experimental Setup for Hearing in Noise Test (HINT)	42
Figure 12	One-Way Interaction Within The Dependent Variable	44
Figure 13	Flowchart for Hearing in Noise Test on the Participants	46
Figure 14	The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow (Moher et al., 2009)	52
Figure 15	Spectral Visualization for The Acoustic Test Fixture (ATF) test Results at 80 dB SPL of noise whereby; (a) Open ear, (b) Occluded ear, (c) Record and Playback and (d) NLMS	60
Figure 16	Spectral Visualization for The Acoustic Test Fixture (ATF) test Results at 90 dB SPL of noise whereby; (a) Open ear, (b) Occluded ear, (c) Record and Playback and (d) NLMS	62
Figure 17	Insertion Loss (dB IL) across Different Ear Condition measured at 500 Hz	65
Figure 18	Insertion Loss (dB IL) across Different Ear Condition measured at 2000 Hz.	66

Figure 19 Signal to Noise Ratio (SNR) Change across Different Ear Condition: (1) The Open Ear, (2) The Occluded Ear, (3) Record and Playback Algorithm and (4) NLMS Filter





## LIST OF ABBREVIATION

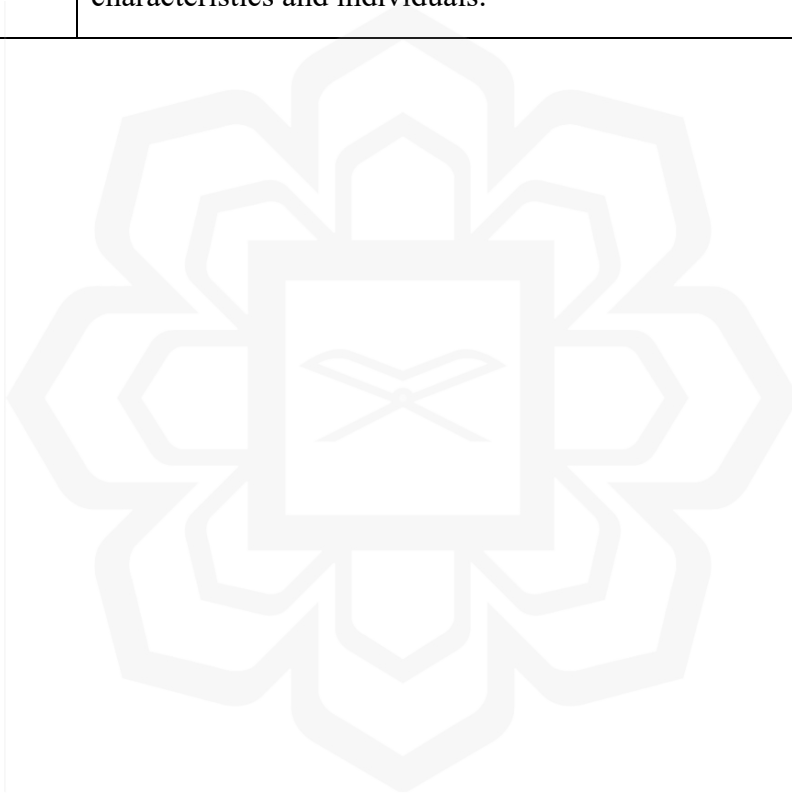
AG	Array Gain
AGC	Adaptive Gain Control
ANC	Acoustic Noise Cancelling
ANOVA	Analysis of Variance
ANR	Acoustic Noise Reduction
ATF	Acoustic Test Fixture
ATS	Asymptomatic Threshold Shift
BS	Backstepping
CRD	Centre for Reviews and Dissemination
dB	Decibel
DNA	Deoxyribonucleic Acid
DOSH	Department of Occupational Safety and Health, Malaysia
DSP	Digital Signal Processor
DSP	Digital Signal Processor
EBM	Evidence-Based Medicine
EEP	Electronic Earplug
e-HPD	Electronic Hearing Protection Device
EPHPP	Effective Public Health Practice Project
FAAF	Four Alternative Auditory Feature Test
FBANC	Feedback Active Noise Control
FPGA	Field Programmable Gate Array
HINT	Hearing in Noise Test
HL	Hearing Loss
HPD	Hearing Protection Device
HTD	Hearing Test Device
IHC	Inner Hair Cell
IUM	International Islamic University Malaysia
IREC	IUM Research Ethics Committee
LMI	Linear Matrix Inequalities
LMS	Least-Mean-Square
MIRE	Microphone-in-Real- Ear
MJIIT	Malaysia-Japan International Institute of Technology
MRT	Modified Rhyme Test
NIHL	Noise-Induced Hearing Loss
NIPTS	Noise-Induced Permanent Threshold Shift
NITTS	Noise Induced Temporary Threshold Shift
NLMS	Normalised Least Mean Square
NRR	Noise Reduction Rating
OHC	Outer Hair Cell

ONIHL	Occupational Noise-Induced Hearing Loss
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Act
PHP	Personal Hearing Protector
PICO	Population Intervention Comparison Outcome
PRGS	Prototype Research Grant Scheme
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PTA	Pure Tone Audiometry
PTS	Permanent Threshold Shift
QuickSIN	Quick Speech In Noise
RASTI	Rapid Speech Transmission Index
REAT	Real-Ear Attenuation at Threshold
ROS	Reactive Oxygen Species
S-HPD	Intelligent Hearing Protection Device
SINR	Signal-to-Noise-Plus-Interference Ratio
SNR	Signal-To-Noise Ratio
SOCISO	Social Security Organization
SPL	Sound Pressure Level
SPRINT	Speech Recognition in Noise Test
SPSS	Statistical Package for the Social Sciences
STI	Speech Transmission Index
TCAPS	Tactical Communications and Protective Systems
TTS	Temporary Threshold Shift
WRS	Word recognition scores

## GLOSSARY

<b>Electronic Hearing Protection Device</b>	The Electronic Hearing Protection Device (e-HPD) is a type of Personal Protective Equipment (PPE) that protects the user from noise. These devices are battery-powered and relying on analogue circuitry or digital processing, or a combination of both (J.G. Casali, 2010b).
<b>Normalised Least-Mean-Square (NLMS) Filter Algorithm</b>	The NLMS filter is an adaptive algorithm developed and applied by researchers to obtain an adaptive filter for active noise cancellation. The NLMS algorithm uses adaptive filter weights according to the incoming audio data as it is being received and used to train the coefficients of the adaptive filter. This algorithm involves the computation of the output of a linear filter in response to the noise reference and the generation of the estimation error between this output and the desired response and accounts for the variation in the signal level at the filter output and selecting the normalized step-size parameter that results in a stable as well as fast converging algorithm
<b>Acoustic Test Fixture</b>	Acoustic Test Fixtures is a device that approximates specific dimensions of an average adult human head and is used according to standards for measuring the insertion loss of hearing protectors. For this purpose, it includes a microphone arrangement for measuring sound pressure levels (Department of Standards Malaysia, 2004).
<b>Acoustic Test Fixture Test</b>	The Acoustic Test Fixture (ATF) Test is a test method utilizing the ATF, a device with the same shape as a human head. The microphone of the ATF is inside the head, and a tube connects the microphone to the outside. The tube has the effect of an auditory canal in a real human ear. The test places the HPD in such a way as to cover the tube's opening fully to ensure that occlusion will occur. The signal analysis used the data from the microphone's output during the analysis process.

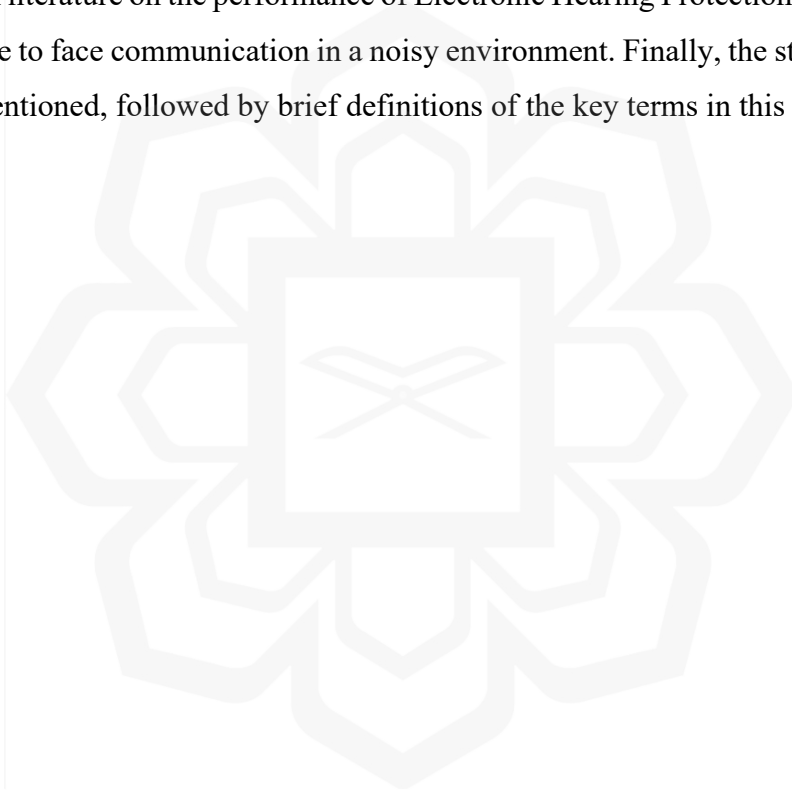
<b>Insertion Loss</b>	Insertion loss is the difference in SPL measured using a microphone at a given location with and without the protector in place (Williams, Reeves, & Chen, 2016). The algebraic difference, in decibels, between the one-third octave band pressure level measured by the microphone of the acoustic test fixture in a specified sound field under specified conditions with the hearing protector absent and the sound pressure level with the hearing protector on with other conditions identical (Department of Standards Malaysia, 2004).
<b>Hearing in Noise Test</b>	The Hearing in Noise Test (HINT) is an adaptive measurement of the speech reception threshold (SRT) used to account for the distortion component of hearing loss and predict speech recognition performance at supra threshold level for a wide range of workplace noise characteristics and individuals.



# **CHAPTER ONE**

## **INTRODUCTION**

This chapter presents and discusses the background of the study. It explains that speech recognition is an essential component for workers in the industry. Additionally, as this study set to discover the performance of the developed prototype in attenuating the noise while allowing the speech to be heard, the problem statement was discussed. This chapter also presented the research questions, hypotheses and objectives. The significance of the study followed, highlighting how this study fills the gap in the research literature on the performance of Electronic Hearing Protection Device (e-HPD) with face to face communication in a noisy environment. Finally, the study's limitations were mentioned, followed by brief definitions of the key terms in this study.



## 1.1 BACKGROUND OF THE STUDY

Hearing Protection Device (HPD) or Personal Hearing Protector (PHP) was legislatively defined as a device worn by a person to prevent unwanted auditory effects from acoustic stimuli (DOSH, 2019). Workers exposed to industrial noise above the 90-dBA are legally obligated to use HPD to reduce the noise exposure (Katz, Chasin, English, Hood, & Tillery, 2015). Recently, Malaysia has gazetted the Noise exposure regulation (2019) under the Occupational Safety and Health Act (OSHA) which specified that worker needs to wear HPD when exposed to 85 dBA of noise.

This requirement was to protect the user from the unwanted effects of noise. One of the unwanted auditory effects of noise is the Occupational Noise-Induced Hearing Loss (ONIHL) or Noise-Induced Hearing Loss (NIHL). Therefore, the immediate mode of protection is by the reduction of the noise going into the user's ears. It can be through the usage of earplugs or earmuffs or a combination of both types of HPDs. These types of HPD is referred to as conventional or passive HPD. However, there are challenges faced using this type of HPD. One of them is that the HPD frequently resulted in blocking out desired speech from reaching the ear (Wagoner et al., 2007). Therefore, the user would face communication difficulties due to passive attenuation of the HPD, reducing all the sound going to the ears, including the possible important speech information such as warnings and critical.

To address this issue, several off-the-shelf HPD, or so-called electronic earplugs (EEP) or Electronic Hearing Protection Device (e-HPD), were developed to allow more effective communication among workers (Lee & Casali, 2017). These typee of HPD increased the usage of e-HPD among workers, musicians, and the military for their high flexibility and multiple functionalities such as active noise control (Brimhall et al., 2002) or adaptive gain control (Hotvet, 1996). e-HPDs commonly have a built-in Digital Signal Processor (DSP) to process the incoming signals in real-time (J.G. Casali, 2010). In addition, the DSPs utilize algorithms to probe with the noise from the environment, such as using Multiband Adaptive Gain control (Voix, Lezzoum, & Gagnon, 2015). Commercially available e-HPD in the Malaysian market primarily uses

the muff type of e-HPD, incorporating technologies such as electronic amplification. However, electronic amplification can only be activated under a pre-determined threshold, thus affecting the communication capability in a noisy environment.

Considering that, International Islamic University Malaysia (IIUM) has developed a conceptual design of an e-HPD as an exploratory attempt to further improve functionality of the e-HPD by incorporating a dual-microphone beamformer with an optimal Wiener post-filtering algorithm into the e-HPD design. However, in a previous study (Selamat, Howe, Tang, & Razali, 2014), the conceptual design implemented applied all of the speech processing algorithms offline. Therefore, the direct implication of the findings to real-time speech processing scenarios may lead to unexpected outcomes. These unexpected outcomes are mainly due to the complexity and extensive computation time required by this algorithm. Besides, several HPD design variables, including but not restricted to the microphone separation distance, number of microphones, types of microphones, and crudely optimized filter parameters used in this study have an affect to the overall performance of the e-HPD.

The conceptual design was then developed into a proof-of-concept e-HPD prototype by incorporating a dual-microphone spatial filtering technique into the e-HPD prototype on a reconfigurable Field Programmable Gate Arrays (FPGA) platform (Oinonen, 2006) to improve workers hearing in noise. Compared to the above mention active HPDs, the main novelty of the prototyped e-HPD is that the spatial filtering technique concurrently processes the noisy speech signals recorded from both left and right microphones to achieve better spatial selectivity of the desired speech. Furthermore, noise suppression was established on the concept that the travelling delay time of noise is larger than the travelling distance and time for the speech signal to reach the microphone array directly facing the speech (Valente, 1999). Therefore, this algorithm could be a substantial potential for the e-HPD to outperform the other noise suppression HPD products. As a result, workers wearing e-HPD could have better speech perception in noise than the other commercial active HPDs. This proof of concept prototype has been developed further by incorporating an adaptive filter as the

algorithm. The development is due to the large size of the proof-of-concept prototype's FPGA platform.

## **1.2 STATEMENT OF THE PROBLEM**

The intended use of the e-HPD prototype was to help industrial workers listening to speech in a noisy environment while protecting them from the harmful effect of loud sound. The performance in cancellation of noise and interference of the Wiener Filter algorithm for the conceptual design has been assessed by computing the array gain (AG). AG represents the improvement of signal-to-noise-plus-interference ratio (SINR) after the speech filtering. This AG was expressed as the ratio of the output SINR to the input SINR. The results show that the proposed dual-microphone beamformer with Wiener post-filter algorithm has been proven to effectively improve the SINR ratio compared to the enhanced Wiener filter. (Selamat et al., 2014).

The e-HPD algorithm successfully improved the spatial selectivity of the recording sensors on the desired speech along the microphone array steered direction. However, the direct implication of the result findings to real-time speech processing scenarios may lead to unexpected outcomes due to the complexity and extensive computation time required by this algorithm. This previous study also did not address the speech understanding of listeners in a noisy environment.

## **1.3 PURPOSE OF THE STUDY**

This study evaluates the performance of the recently developed IIUM e-HPD prototype in noise attenuation and speech intelligibility scores.