TTT4250 - Acoustical Measurement Techniques

Hearing - Test and Comparison of Pure Tone audiometry (PTA) and New Early Warning Test (NEWT)

performed by

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Summary

This report will highlight two methods of testing humans for hearing loss. This is done via the New Early Warning Test(NEWT) and Pure Tone Audiometry (PTA). Newt is a quick and automatic test method, while the PTA depend on trained audiologists to conduct the test using an audiometer. The NEWT method serves as an effective way of regularly testing the hearing for hearing loss so to early detect any significant hearing loss and thus seeking help from trained professionals that can conduct a PTA that test each ear individually, compared to the NEWT method that test both ears simultaneously. Through the NEWT test, the sum of the average attenuation of two standard hearing protecting devices, earplugs and earmuffs, was found to be, respectively, 45.5dB and 45.1dB. There was a total of 11 participants in this lab.

Contents

1 Introduction

According to the World Health Organization (WHO), over 5% of the worlds population require rehabilitation to address their disabling hearing loss (hearing loss of more than 35dB), and these number are expected to grow to 10% within 2050[1]. A reason for hearing loss is exposure of high sound levels over time, which is often the case at specific construction sites, workshops, concerts, and more. There exist many options to prevent hearing loss due to high sound levels, and these are called hearing protection devices (HPDs). They come in various forms and shapes, but the most common are earmuffs and earplugs. Even with proper HPDs, there will always be a risk of hearing loss, either from exposure to high sound levels or due to medical conditions and injuries. Hearing loss can have an affect on the quality of life, which makes it important to early being able to detect hearing loss so to be able to prevent further harm. This lab will therefore focus on two separate ways of evaluating the human hearing. The first method is the classic Pure Tone Audiometry (PTA) followed by the New Early Warning Test (NEWT) created by SINTEF. A total of 11 participants will take part in the lab, and the difference between the two methods will be discussed and visualized graphically. The expanded uncertainty as well as the attenuation of two standard HPDs will be calculated as well using the NEWT method.

2 Theory

This section will cover the necessary theory related to the two test methods, NEWT and PTA, and some general theory about hearing loss, how the ear works, attenuation and some general statistics.

This section will cover the necessary theory to understand the two tests done to assess the quality of hearing for the different subjects, as well as give some general theory about hearing loss as well as briefly how the ear works.

2.1 The Hearing System and how it works for humans

The human ear is a system consisting of three parts, as shown in Figure 2.1, the outer ear, the middle ear and the inner ear[4]. The human ear is a very efficient transducer that convert the air pressure hitting the eardrum into a neural-electric signal from the cochlear nerve that the brain translates into the sound we humans hear every day. The outer ear consists of three major parts, the earlobe, the auricle and the auditory canal. The function of the auricle is to guide the sound waves towards the auditory canal where the pressure eventually meets the eardrum, and thus entering the middle ear.

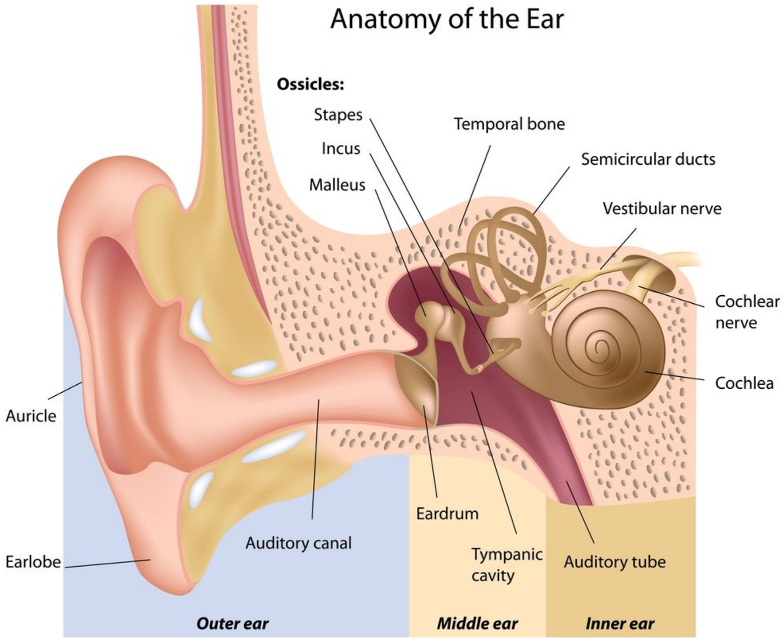

Figure 2.1: Illustration of the ear and its anatomy.

The middle ear has the function to transfer the vibrations at the eardrum to the cochlea where the vibrations is translated into frequencies. This is done using three bones, the malleus, incus and stapes, all located in the middle ear. There is also a tympanic cavity in the middle ear, which is connected to the auditory tube, also called the eustachian tube, which is connected to balance. The relative pressure between the tympanic cavity and the auditory canal decides how freely the eardrum vibrates. The effect of this is often felt when sitting inside an airplane during take-off, where the relative pressure changes and the pressure inside the tympanic cavity must either decrease or increase to stabilize.

The cochlea is a hollow, spiral-shaped bone found in the inner ear, and its rather like a snail-shell in its shape. It's a long bone that gets thicker by the length. because of its long shape, the pressure transduced from the eardrum will propagate differently along the cochlea, and it will here be translated into different frequencies, remarkably like how the Fourier Transform transforms a signal in the time domain into specific frequencies in the frequency domain. This results in a tonotopic map that allow humans to perceive various frequencies of sound. The vibrations propagate inside the cochlea in a fluid known as endolymph, which is found in the cochlear duct. The vibrations stimulate the hair cells inside the structure known as the organ of Corti, where the mechanical stimulation of hair cells is converted to electrical impulses. The vestibulocochlear nerve then carries the nerve impulses to the brain, where the brain interprets the signals as sound.

There exist both inner-and outer hair cells in the cochlea. The inner hair cells pick up the vibrations and transform them into nerve signals as mentioned above, but the outer hair cells serve a different purpose. The outer hair cells change in length with the movement of the inner hair cells, which help amplify low-level signal. As mentioned, the cochlea responds differently to different frequencies due to its long shape that increase in thickness with the length. The high frequencies excite the cochlea near the base while the lower frequencies have a longer wavelength and thus excite the cochlea at the apex.

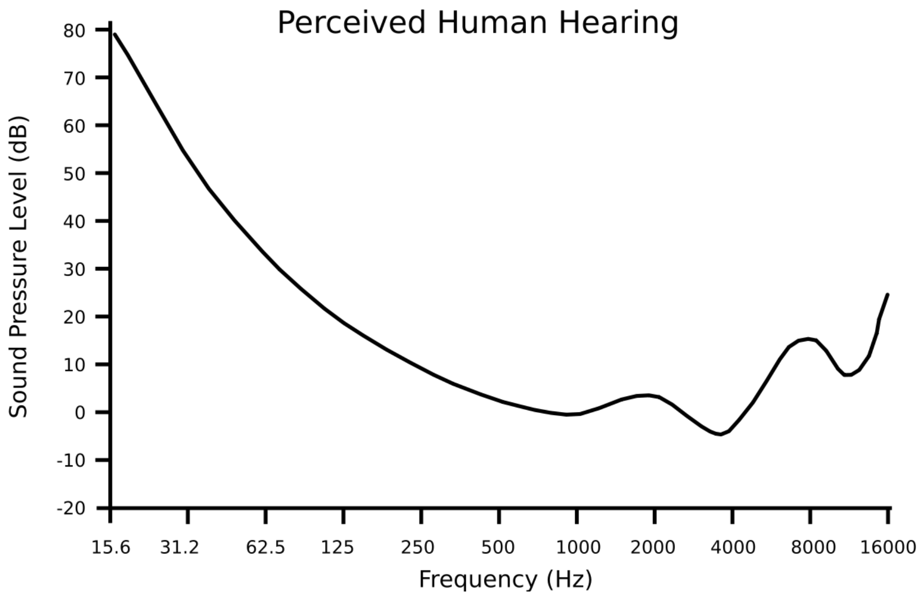

Figure 2.2: Perceived human hearing as a function for the audible frequency range for humans.

A normal human being has an audible hearing range, measured in frequency, of 20Hz-20KHz with a dynamic range of 120 dB ref. 20μPa, where the reference value for the logarithmic scale is 20 μPa.

The human hearing is not linear for all frequencies. This creates a graph that show the perceived human hearing graph, as seen in Figure 2.2. Due to the auditory canal working as a tube, the human ear has certain frequencies that are enhanced due to resonances in the auditory canal. These can be clearly seen as the lower points on the curve around 3KHz, 9KHz, and so on. 1KHz is the frequency that are perceived exactly as it is, as can be seen from the curve. The graph also show that the lower frequencies are less audible for normal humans, meaning that these frequencies must be enhanced for humans to perceive it as equally loud as, for example, frequencies around 1KHz.

2.2 Hearing Loss

Hearing loss come in two broad categories: Sensorineural hearing loss and conductive hearing loss. Sensourineural hearing loss occurs when there is damage to the inner ear or the auditory nerve and is in most cases permanent. Conductive hearing loss is when the sound waves can't reach the inner ear. This may be due to blocking in the outer ear, such as earwax buildup, fluid, or a punctured eardrum. The conductive hearing loss is often solved with medical treatment or surgery.

Other types of hearing loss are tinnitus, which is described as a constant ringing in the ears, but can also sound like roaring, clicking, hissing or buzzing. Hearing loss is also a natural phenomenon that comes with age, and these types of hearing loss are called presbycusis. Presbycusis make it hard for humans to tolerate loud sounds and make it hard to distinguish normal speech, making it hard to hear what others are saying. This type of hearing loss will come gradually and can be treated with hearing aid.

If a person deviates from the perceived hearing curve as shown in Figure 2.2 with more than 20dB, the person is said to have hearing loss. The degree of hearing loss is decided by how much the hearing threshold vary to the curve for normal hearing. The different degrees of hearing loss is stated in Table 2.1.

Table 2.1: Degree of hearing loss[2]

Degree of hearing loss	Hearing threshold [dB]
Normal	-10 to 15
Slight	16 to 25
Mild	26 to 40
Moderate	41 to 55
Moderately severe	56 to 70
Severe	71 to 90
Profound	91+

2.3 Pure Tone Audiometry (PTA)

Pure tone audiometry (PTA) is a way of evaluating the hearing of a human subject by exciting specific frequencies at different sound levels through a calibrated pair of headphones, to find the lowest threshold where the sound is audible to the test subject. The method tests each ear individually so to better log the hearing capability of both ears separately. Something to consider when doing such tests is cross hearing. When sound is applied to one ear, the contralateral cochlea can feel the vibrations through the bone of the skull, and in that way detect sound in the opposite ear of what is being assessed. This is known as cross hearing. When testing either the right-or left ear, the one conducting the test on the test subject will excite either the left or right ear with a tone at a given frequency (normally either 500, 1000, 2000, 4000 or 8000Hz) and a sound level. The test subject will then acknowledge whether the tone was audible or not with the use of a hand-held button. If the tone was audible, the performer lowers the sound level with a fixed level, usually 5dB, and the tone is again excited in a short burst. This is repeated until the test subject does not positively respond to a tone. The sound level is then increased with a value two times larger than what was used to decrease the sound level with. This is repeated until the lowest sound level where the test subject found the tone to be audible of minimum two out of three times.

There exist several parameters that can change the results from this, or any type of hearing test. If the test subject listened to loud music before the test is performed, stress, general shape of the test subject and more. There exist two kinds of shift, also related to the two general types of hearing loss mentioned previously. Temporary Threshold Shift (TSS) and Permanent Threshold Shift (PTS). The temporary is usually the result of the previously mentioned reasons as to why the hearing test can result in shifted results, but the permanent ones show, as mentioned before, permanent hearing loss.

2.4 New Early Warning Test (NEWT)

The New Early Warning Test (NEWT) has the same purpose as the PTA method but differ in how it is performed. NEWT is an automated method developed by SINTEF and NTNU in 2014. Same as for the PTA method, it uses tones in octave band steps from 125-8000Hz. The burst of the tones is rather smaller than for that in the PTA method, with a duration of 150ms with 2 signals used for each instance. The tones are also faded in and out with the duration of 10ms using raised cosine fade in-and out. The idea was to increase the attention of the test subject because it was proven that long, and constants tones had the effect on the test subject of making them less concentrated and exact. The NEWT method then changes that and make the test subject more responsive and grant a more stable response. The order of which tones are played are randomized, but with the goal of finding the psychometric function that best represent the hearing level of the test subject. The psychometric function is a way of representing an error with a given standard deviation and range. This is used in the NEWT method by setting a start range where the center of the y axis is the maximum probable hearing level, HL. A visual representation of how the sound level threshold is found with the NEWT method can be seen in Figure 2.3.

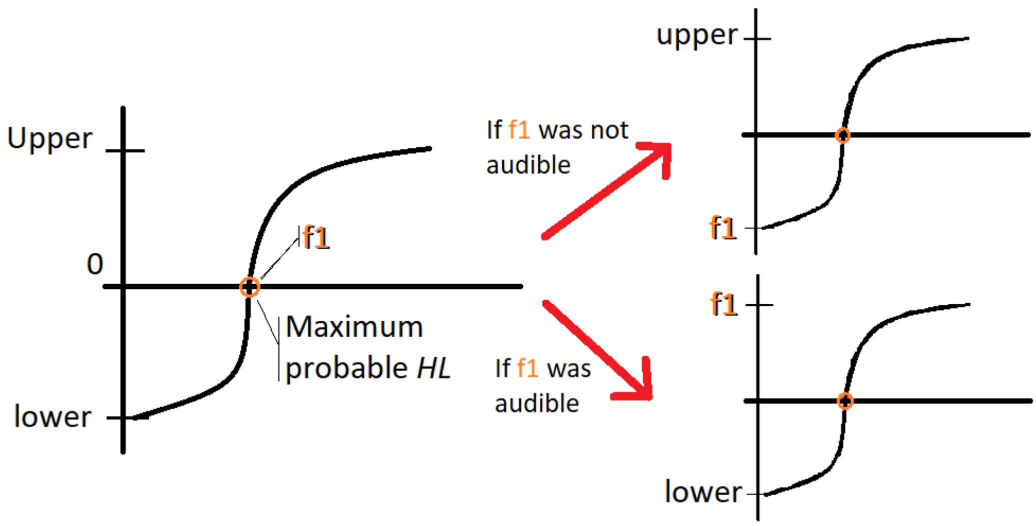

Figure 2.3: Visual representation of how each step of the NEWT method is performed. A starting range is set, and whether the tone was audible or not, the next range is set with the upper or lower bounds replaced with $f1$, the maximum probable hearing level for the given range, marked with an orange circle.

This process is repeated until the lowest hearing range is found, with the HL for the given frequency given as the largest probable HL. The probability is at 50% for the largest probable HL, which is the reason this value is chosen when setting the next boundary.

2.5 Attenuation of Hearing Protectors - NS-EN 352-2:2002

The two most common hearing protector devices (HPDs) are over-the-ear and in-ear. The ones that are over-the-ear are usually a housing having sound absorbent material and a barrier between the head and the HPD made of foam so to sit comfortably. The in-ear are in its most simplistic shape, a foam that first are minimized in size by rolling it, and then inserted into the auditory canal where the foam expands and fill the auditory canal with the sound absorbent foam. The in-ear ones can also be perfectly molded to fit the users auditory canal, but these are also more expensive. HPDs come both in passive and active models. The passive ones rely solely on the sound absorbent material, while the active ones take use of microphones and speakers to create destructive interference so to mask the noise and remove unwanted noise. These type of HPDs are also created in the same way as the passive ones to a certain degree, so to not only relying on the active effect, but rather a mixture of both. The HPDs used for this lab is made according to the standard NS-EN 352-2:2002 [5] and it states that the attenuation of HPD must not be below the values shown in Table 2.2 for the specific frequency.

Table 2.2: Minimum attenuation according to NS-EN 352-2:2002. M_s is the mean attenuation and s_f is the standard deviation measured according to EN 13819-2:2002

Frequency [Hz]	[Hz](M_s-s_f) [dB]
125	5
250	8
500	10
1000	12
2000	12
4000	12
8000	12

The attenuation can be calculated in many ways, and one standardized way is described in ISO 4869-1:2018. In this lab, the mentioned method will not be used, but rather the NEWT method. The Attenuation is calculated as

$$Attenuation = HL_{\text{with HPD}} - HL_{\text{without HPD}} \tag{2.1}$$

where HL is the hearing level.

2.6 Uncertainty and statistic

Since the measurements from all groups is viewed as equivalent repetitions, the uncertainty type is set to be of type A, meaning it is random. The expanded uncertainty is then calculated by first finding the experimental standard deviation, $s(h_k)$, as

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \overline{X})^2} \tag{2.2}$$

where $(X_i - \overline{X})$ is called the residual, or the deviation from the mean, for each measurement, and $(N-1)$ is the degrees of freedom for the measurement.

The expanded uncertainty, U, can then be found as

$$U = k \cdot \frac{s}{\sqrt{N}} \tag{2.3}$$

where k is the coverage factor decided by the degrees of freedom.

3 Method and Equipment

This section will cover in detail how the measurements were performed, a description of the equipment used as well as include illustration of the setup. The lab were performed at SINTEF's facilities at Strindvegen 4, Trondheim. This lab had a permanent room for both PTA and NEWT, with the necessary equipment. A list of the equipment can be found in Table 3.1.

3.1 Equipment

Table 3.1: List of equipment used for the lab.

Equipment	Model Number	Serial Number
Clinical Audiometer	Orbiter 922 V.2	
Headphones	Sennheiser HDA 200	
Loudspeakers	Custom to lab facility	
Computer running the NEWTS software	Custom to lab facility	
Amplifier	Custom to lab facility	
Earmuffs	Found at the lab facility	
Foam earplugs	Regular foam	

3.2 Pure Tone Audiometry (PTA)

To perform the PTA test, an audiometer was used. A block diagram showing how the PTA test is setup can be seen in Figure 3.1. This was in a sound insulated room at the lab. The audiometer was calibrated according to ISO 389-1:2017, and was calibrated latest at 21.01.2020. The test subject was placed in a chair, facing away from the audiometer, and was given a handheld device having a button on top and a pair of headphones to put on. It is important to note the correct placement about left-and right, written on the headphones. The test conductor is then seated at the audiometer, and a start value for the sound level is chosen. For this test, assuming both participants have normal hearing, the start value was set to 25dB so to reduce the number of iterations. The step value when decreasing the sound level was set to 5dB. The test is then performed as described previously, and the HL are noted using excel. The test is performed for both ears, and then the test subject switch place with the test performer so that both can be evaluated with the PTA method.

The frequency range of test where the octave band frequencies from 500-8000Hz. Afterwards, an audiogram, a curve showing the thresholds as a function of frequency, can be plotted.

3.3 New Early Warning Test (NEWT)

The NEWT test was performed in a special room that had a layout of four speakers, one in each corner, and a chair found in the center of all the speakers. An illustration of the NEWT setup is seen in Figure 3.2. The room was soundproof, and a sound proof window was strategically placed such that the test subject and test conductor has free view to one another through the glass. First,

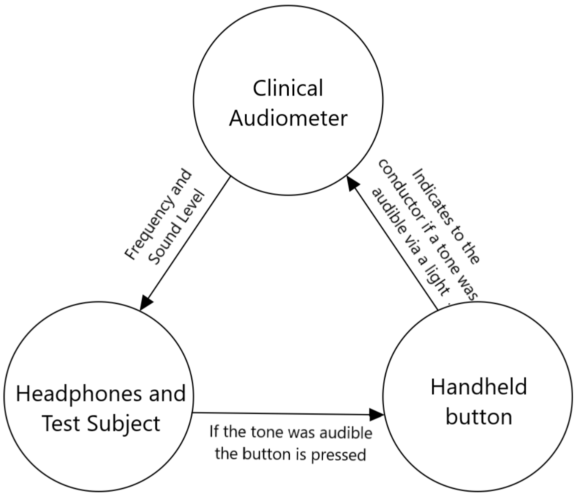

Figure 3.1: Block diagram of how the procedure for the PTA test is performed. The test conductor uses the clinical audiometer(Top-most circle) to send a frequency of a given sound level to the headphones, placed on the head of the test subject. Whenever the test subject hears a tone, the handheld button is pressed which send a signal to the clinical audiometer, that show a positive signal by turning on a light on the audiometer.

test subject A put on a pair of standard earmuffs and took a seat in the test room. Same as for the PTA method, a handheld device with a button on top was used so that the test subject could show when a tone was audible. After the program was started, the test begun when the test subject pushed the handheld button for the first time.

After the test subject A was done, test subject B put on a pair of standard foam earplugs, and did the test in the same manner as subject A. Lastly, both subjects did the test without any HPDs so that the attenuation could be calculated later, and the test results could be compared to the PTA method.

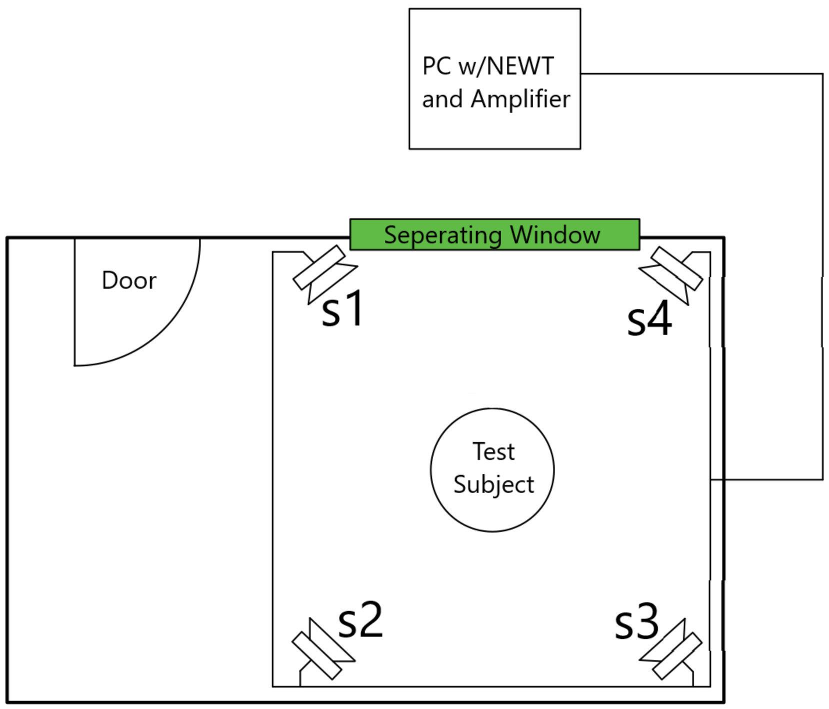

Figure 3.2: Setup of the NEWT system. The top-most box shows the location of the operator as well as the PC running the NEWT script. The signal is also amplified and sent to the four speakers by enumerated s. In the center of the four speakers is a chair as to where the test subject will be seated. The green bar shows the position of the separating window, allowing the operator and test subject to see one another. The quarter of a circle inside the NEWT room is the door into the soundproof room.

4 Results

This section will present the results from the lab as well as present some values used in the post processing.

4.1 PTA and NEWT for the Two Test Subjects

The lab was performed in groups of two. A comparison of both the NEWT and PTA method for both test subjects can be seen in Figure 4.1.

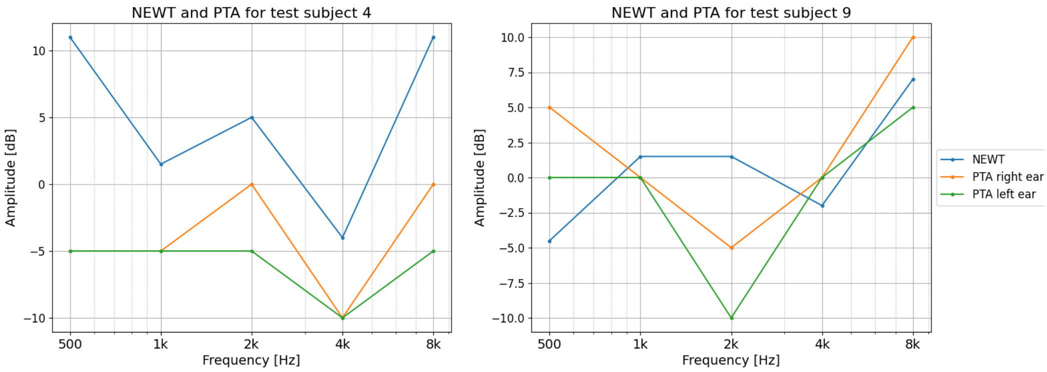

Figure 4.1: Comparison of the NEWT-and PTA method for test subjects 4 and 9.

It is evident from Figure 4.1 that for subject 4, the graph for the NEWT and PTA method have a similar shape, but show a vast difference at 500Hz. For test subject 9, the difference is less visible, showing signs of more even results.

4.2 Attenuation and Expanded Uncertainty

The attenuation for the NEWT method using HPDs were calculated using Equation (2.1). To show the average attenuation as a function of frequency, the values for all test subjects was averaged logarithmic and plotted as seen in Figure 4.2

A total of 11 participants performed the lab for both PTA and NEWT method. To evenly distribute the participants on both earplugs and earmuffs, some participants did the NEWT test with both earmuffs and earplugs. This gave a total distribution of seven participants on both earplugs and earmuffs. By looking at the k values for the t-student distribution with a degree of freedom as 7, the coverage factor was set to $k = 2.365$, corresponding to a two tailed t-distribution with a 95% confidence interval.

All the test subjects as well as the expanded uncertainty for both earplugs and earmuffs are seen in Figure 4.3.

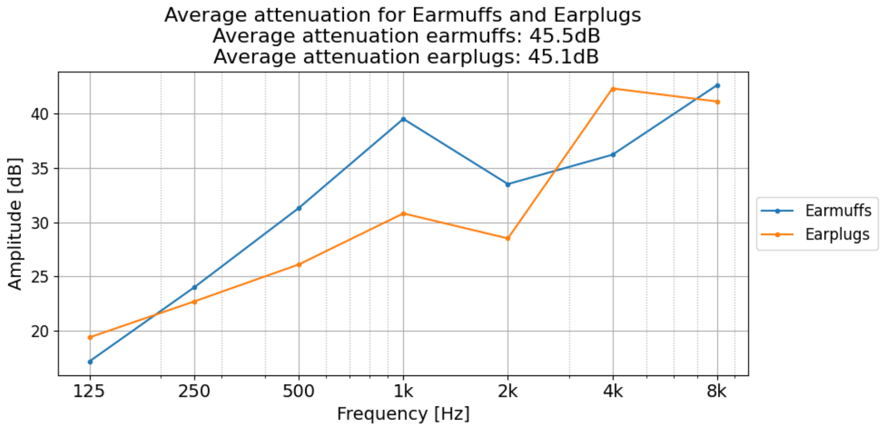

Figure 4.2: Average attenuation for the earplugs and earmuffs used in the lab.

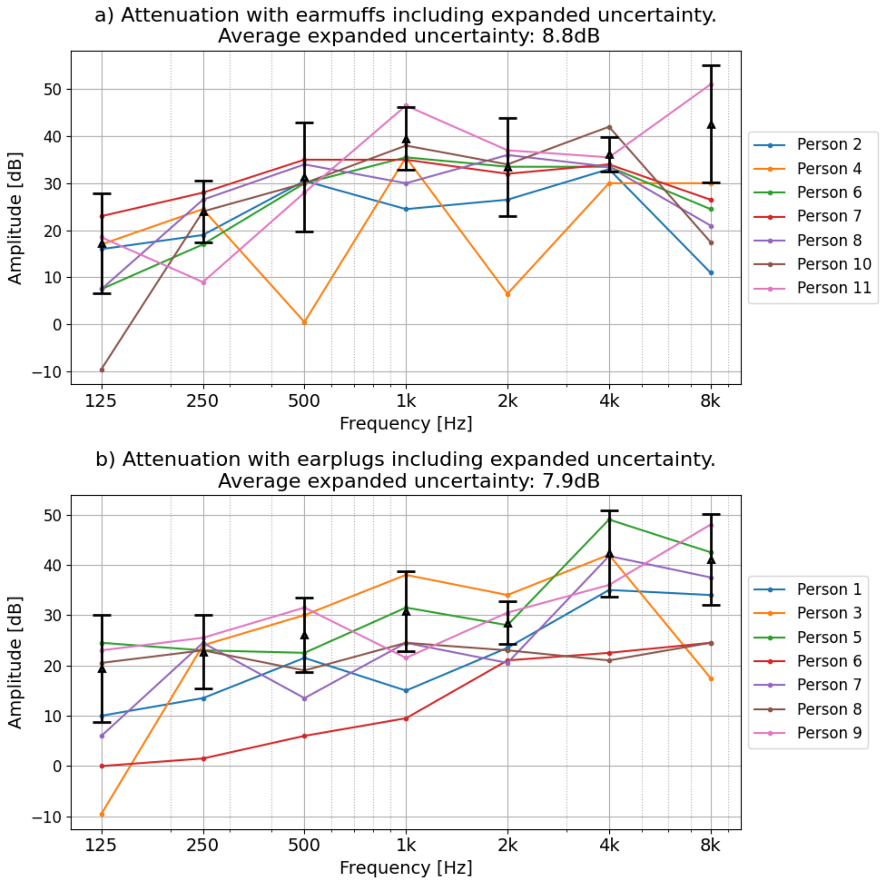

Figure 4.3: a) and (b) show the expanded uncertainty, marked in black, with all the test subjects, marked in different colors, as a function of frequency for, respectively, earmuffs and earplugs as HPDs. The average expanded uncertainty for the two are 8.8dB and 7.9dB for, respectively, earmuffs and earplugs.

5 Discussions

From Figure 4.1 it is evident that both participants have normal hearing. But by comparing the PTA with the NEWT method, the difference can be significant. For test subject 4, The general shape of both the PTA and the NEWT method looks to be quite equal. The newt method is for all frequencies higher in amplitude than the PTA method with a minimum difference of 5dB. For test subject 9, the values and shape for NEWT and PTA differ more and show a higher inconsistency for both methods. It should be noted that none of the test conductors are trained professionals, and this is the first time, for them both, that they conduct a PTA test. The downside with the NEWT method is it that it does not evaluate each ear separately, but rather at the same time. This will make it harder for the NEWT method to pick up any individual hearing loss for both ears, compared to the PTA method. Since the PTA method is done purely manual, the room for error here is significant. The test conductors are mere students and have not been professionally thought how to use the clinical audiometer, nor have they any experience performing a PTA test. The room where the NEWT test was performed was not completely silent either and had a minor noise in the background which made it harder to separate the excited sound from the background noise for the lowest levels. It should also be mentioned that the NEWT method is new, and neither of the two test subjects have tried it before. This made the test substantially different from the PTA method they both were familiar with, and that they might not have been properly known to what they should listen for. Since the NEWT method excites the tones in a different manner than what done in the PTA method, every scenario in the NEWT method new to the test subjects. Considering that the difference between the NEWT and PTA method is not vastly different, the NEWT method serves as an easy and quick replacement for the PTA method just to check the general level of hearing loss. If the NEWT method gives results that show sign of hearing loss, it could be clever to then send the test subject to do a PTA test.

From Figure 4.2 it is evident that the earmuffs had a higher attenuation for the 250-2000Hz range, and with the difference going as high as 9dB in the 1KHz band. It is also clear that the earplug has a higher attenuation at 4KHz as well as 125Hz. The high difference at 4KHz may be due to the earplug filling the entire auditory canal, while the earmuffs only cover the ear. This might give room for the resonance frequency in the auditory canal to enhance the sound leaking through the earmuffs, while the foam inside the auditory canal might inhibit the resonance frequency to enhance to the same extent.

The expanded uncertainty seems reasonable considering the vast difference in result values. The error is lowest for both earplugs and earmuffs at 1-4KHz.

To summarize the error margins, the lab was not done by professionals leaving room for human errors to a vast extent. The NEWT method was new to the test subjects, which made them rather focused and not prepared for how the sounds actually sounded like. There was also background noise inside the NEWT chamber that also affected how low it was audible to detect the excited tones from the speakers.

6 Conclusions

The NEWT method is a method that is quick and easier to perform than the PTA method that requires a trained audiologist. The NEWT method cannot serve as a replacement for the PTA method, but rather be a quick test for subjects to check for hearing loss on a general level. This reduces the time and need for trained audiologists, and that they can rather be used for the cases where the NEWT method shows sign of hearing loss. For construction sites or other sites where high sound levels are produced, a test station running the NEWT method would be an uncomplicated way to consistent test the workers hearing and detect any considerable damage early to further be sent to trained professionals for a more detailed check. The NEWT method serves therefore as test that can be conducted regularly to early detect hearing loss damage, but it is not an entirely supplement to the PTA method. The sum of the average attenuation were found to be 45.5dB and 45.1dB for, respectively, earmuffs and earplugs which satisfy the requirement in Table 2.2.

Bibliography

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[5] NS-EN 352-2:2002, Hearing Protectors - General Requirements - Part 2: Ear-plugs, 06.12.2002

A Appendix

Table A.1: Values from the NEWT tests.

Test Subject	Test Type	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
1	NEWT without HPD	3	-0.5	-0.5	-2	-0.5	-4.5	11
	NEWT with earplugs	13	13	21	13	23	30.5	45
2	NEWT without HPD	-5	-0.5	-4.5	-4	3	-5	13
	NEWT with earmuffs	11	18.5	26	20.5	29.5	28	24
3	NEWT without HPD	5	11	15	3	9	3	3
	NEWT with earplugs	-4.5	35	45	41	43	45	20.5
4	NEWT without HPD	3	1.5	11	1.5	5	-4	11
	NEWT with earmuffs	20	26	11.5	37	11.5	26	41
5	NEWT without HPD	-0.5	3	7	1.5	-2	-0.5	11
	NEWT with earplugs	24	26	29.5	33	26	48.5	53.5
6	NEWT without HPD	1.5	1.5	3	1.5	-4	-2	5
	NEWT with earmuffs	9	18.5	33	37	29.5	31.5	29.5
	NEWT with earplugs	1.5	3	9	11	17	20.5	29.5
7	NEWT without HPD	3.0	1.5	7.0	5.0	5.0	5.0	20.5
	NEWT with earmuffs	26	29.5	42	40	37	39	47
	NEWT with earplugs	9	26	20.5	29.5	25.5	46.75	58
8	NEWT without HPD	1.5	3	5	1.5	3	-0.5	5
	NEWT with earmuffs	9	29.5	39	31.5	39	33	26
	NEWT with earplugs	22	26	24	26	26	20.5	29.5
9	NEWT without HPD	-2	3	-4.5	1.5	1.5	-2	7
	NEWT with earplugs	21	28.5	27	23	32	34	55
10	NEWT without HPD	5	11	15	3	9	3	3
	NEWT with earmuffs	-4.5	35	45	41	43	45	20.5
11	NEWT without HPD	-2.0	11.0	11.0	-3.5	13.0	9.0	-4.5
	NEWT with earmuffs	16.5	20	39	43	50	44.5	46.5

B Appendix

Table B.1: Values from the PTA tests.

	Right ear					Left ear				
	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
1	0	-5	-5	0	5	-5	-5	-10	5	5
2	0	0	-5	0	10	-5	0	0	-5	10
3	5	-5	-5	5	0	5	5	-5	5	0
4	-5	-5	0	-10	0	-5	-5	-5	-10	-5
5	0	-5	-10	0	0	0	0	-5	5	5
7	5	5	0	5	25	15	15	25	55	65
8	0	-5	5	0	-10	0	-10	10	0	-10
9	5	0	-5	0	10	0	0	-10	0	5
10	5	-5	-5	5	0	5	5	0	-5	10
11	0	5	10	15	15	10	15	20	20	5