Impact of the ambient sound level on the system's measurements CAPA

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CAPA is software used for the monitoring of the Attenuation of hearing protectors.

This study will investigate the impact of noise associated with the sound environment on the measurement of hearing thresholds of subjects tested by the CAPA system.

In this study, we will see that the higher the noise level, the less reliable the measurement is. Sound degradation, which occurs quickly, results in a loss of attenuation of the protector.

Efficiency monitoring of HPD

F-102.2

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1 Introduction

The CAPA software can monitor the effectiveness of an in-ear hearing protector, whether it is a customized protector, disposable earplug, or reusable earplug.
Thus, if an employee exposed to noise uses his hearing protectors properly at 100% of the duration of noise exposure, he will be perfectly protected.

The CAPA software, developed by HearingProTech®, measures the actual attenuation of the HPD (Hearing Protection Device) of the user.

The measure is based on the principle of a subjective audiogram test, that is to say the research of hearing thresholds (minimum sound pressure level that must be imposed for the sound to be heard by a subject). To measure the attenuation of a hearing protector, CAPA calculates the difference between hearing thresholds with and without hearing protectors worn by the user. The attenuation in dB is recorded by octave band.

To address the hearing thresholds, the system emits sounds characteristic to the desired frequencies via headphones. The intensity of the emitted sound is increased. As soon as the user perceives the signal, he signals using a buzzer.

This measurement is subjective and based on the detection of low intensities. It is understood that the sound environment can have a significant impact on the test results.

This study will investigate the impact of noise associated with the sound environment on the measurement of hearing thresholds of the CAPA method.

2 Equipment and methods

2.1 Framework of the study

Attenuation is the difference between hearing thresholds with and without hearing protectors worn by the user.

We hypothesize that in noise, the measurement of hearing thresholds without hearing protection is affected more significantly than hearing thresholds with hearing protection.

To confirm this hypothesis, a series of tests was carried out on a subject. The graphs below represent the absolute differences between a measurement without added noise (optimal conditions) and measurements with added noise (noise exposure conditions will be detailed in section 2.4).

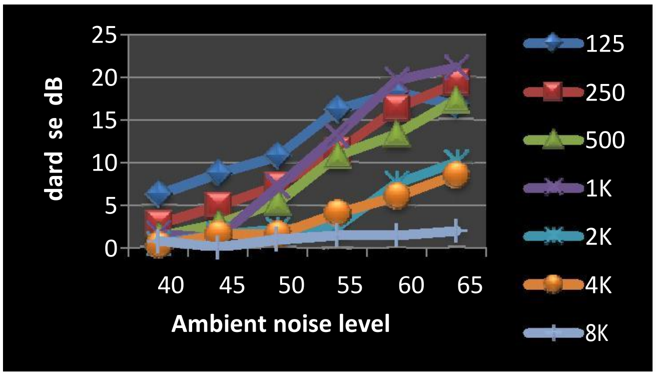


Figure 1: Differences observed on the measurement without hearing protectors

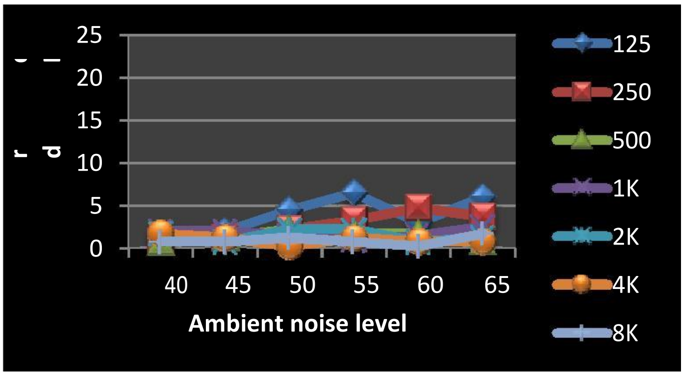


Figure 2 Differences observed on the measurement with hearing protectors

We note that the CAPA measurements with hearing protectors (COTRAL Micra3D® XS18) are hardly affected by environmental noise.

		63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	HML (dB)		SNR(dB)
XS18	Mf (dB)	13,0	14,6	17,8	24,6	24,2	32,9	35,2	34,1	H	26,2	
	Sf (dB)	5,9	5,4	5,3	3,8	5,1	5,1	5,1	7,3	M	20,1	23
	APVf (dB)	7,1	9,1	12,5	20,8	19,2	27,8	30,1	26,8	L	14,9	

Table 1 Mean, standard deviation, and APV of the hearing protector used.

Given this assumption, and in order to limit the influence of hearing protectors on this study, we shall only study the results of the measurements without hearing protection.

2.2 Population

For this study, 12 subjects participated in the tests. All were selected for their good hearing, their knowledge of the CAPA test, and good repeatability of results with previous tests.

The subjects were between 21 and 41 years, and the average age is 31 years. The sample pool comprised 5 women and 7 men.

2.3 Measurement of attenuation of the ear muffs

The helmet used by the CAPA method has two functions: diffuse the sounds that will be detected by the subject, and filter spurious noise to the maximum extent.

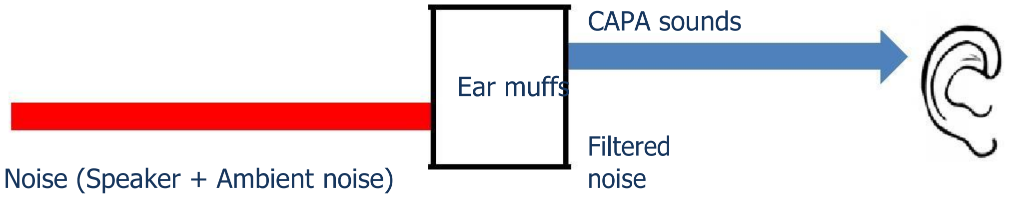


Figure 3: Action of ear muffs

We will measure the attenuation of the ear muffs used by the CAPA method (Beyerdynamic DT-770-M ear muffs, measurement performed using an artificial ear (microphone) connected to a Svantek Svan 979 sound level meter).
The attenuation of the ear muffs is the difference between the acoustic pressures measured by the sound level meter with and without ear muffs positioned on the microphone of the artificial ear.

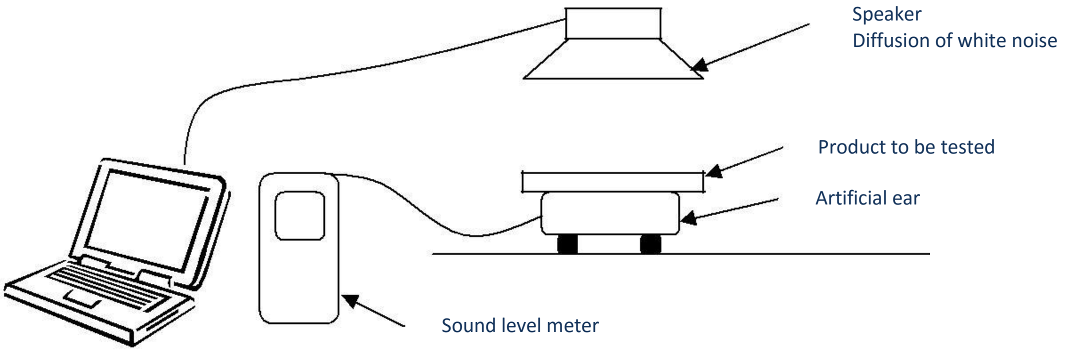


Figure 4: Measurement method

To determine an average attenuation, we rely on four measurements and on two different devices in different volumes.

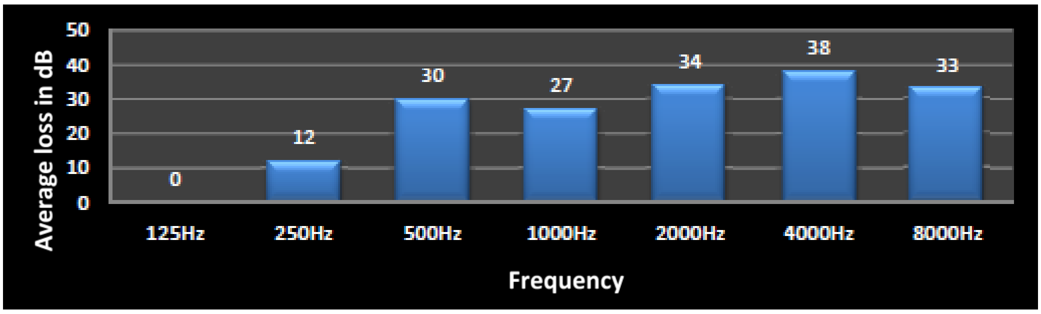


Figure 5: Attenuation of the ear muffs per octave band

We observe that the ear muffs are particularly effective in filtering the medium/high frequencies. However, the low frequencies are not attenuated.

2.4 Conditions of the study:

2.4.1 Acoustic room

The tests are performed in a room with enhanced soundproofing. However, the room was not designed to deal with structure-borne noise transmitted through the floor.
The table below shows the ambient noise levels in the room in silence (no artificial noise added):

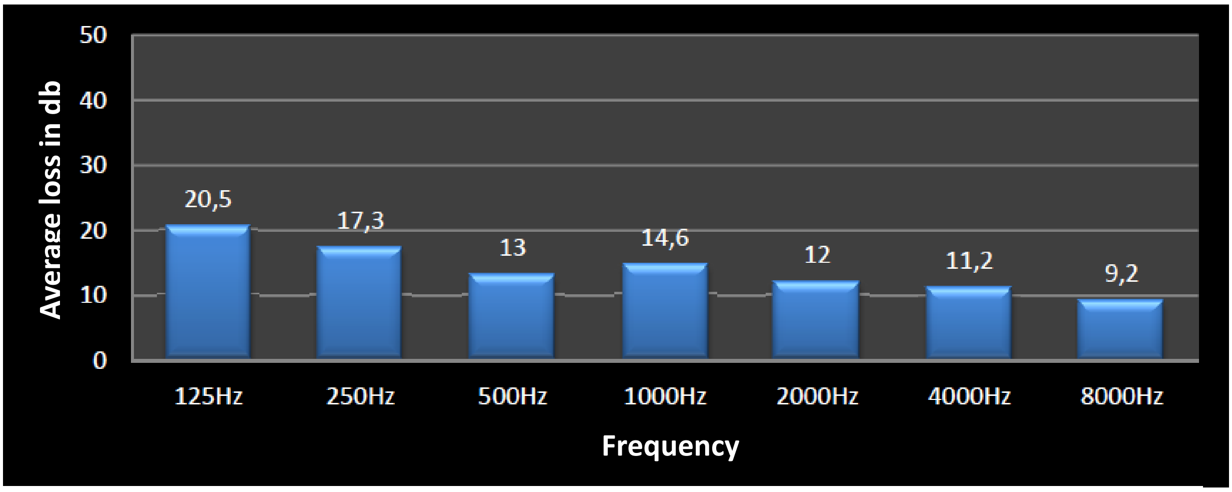


Figure 6: Ambient room noise. expressed in dB is measured by octave band

The noise level is higher at the frequency 125 Hz. This is due to spurious noise generated by the amplifier for diffusing sounds.

2.4.2 Protocol:

The subject is equipped with CAPA headphones and a buzzer. In a basic CAPA test, a characteristic sound of a given frequency is transmitted via headphones. The loudness of the sound output gradually increases. The user is prompted to press the buzzer at the moment the broadcast sound is audible to him. In this way, the system measures the user's hearing thresholds. In the CAPA method, the hearing thresholds of both ears are separated.

For this study, we will measure the hearing thresholds several times (without hearing protectors), exposing the subject to different noise levels (reference noises described in section 2.4.3). We want to study the impact of noise on the results of the CAPA method.

The sounds are broadcast via an amplifier (t.amp PA 4080 80W RMS) and two 10-inch speakers.

There are left and right speakers, each placed at approximately 1 meter from the subject, according to the following diagram:

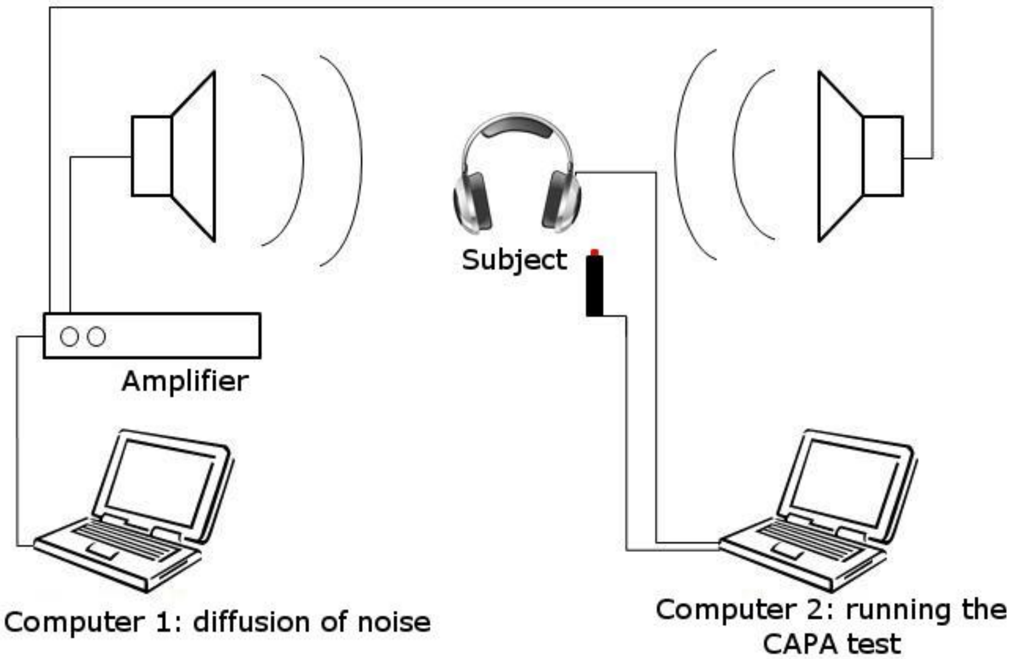


Figure 7: Hardware requirements

- Artificial noise broadcast via computer 1.
- The measured hearing thresholds are recorded on computer 2.

2.4.3 Synthesized sounds

All frequency readings of this report have been measured using the Svantek Svan 979 sound level meter, with the following measurement parameters:

- ➔ LEQ measurement (Level Equivalent), the average acoustic energy over time
- ➔ Integration period of the measurement: 10 seconds
- ➔ A-weighted filter (measurement corrected based on the sensitivity curves of the human ear)

In the graph below are given several non-comprehensive noise surveys in a company:

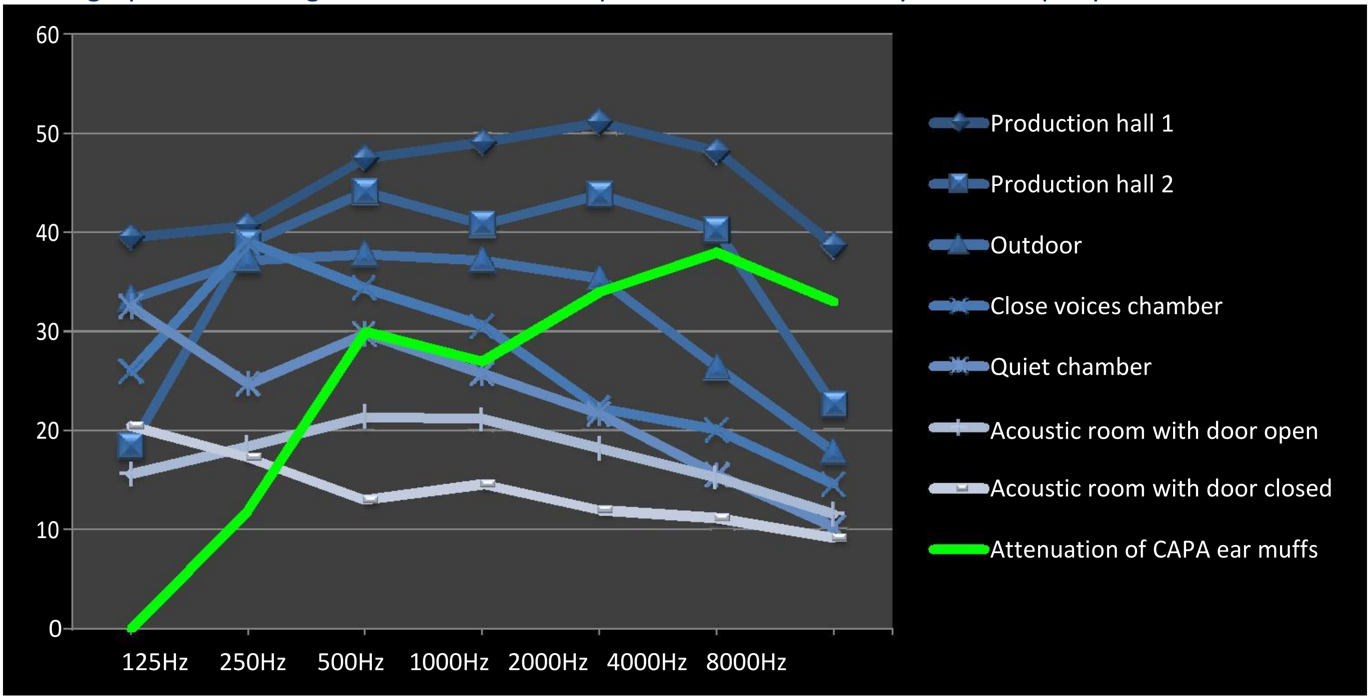


Figure 8: Some sound recordings to assess the levels of noise to be simulated

We tried to diffuse close noise around this scale. We will simulate the conditions of use of CAPA, by generating noise at several volume levels.

During these tests, the subjects will be exposed to the following 6 reference noises:

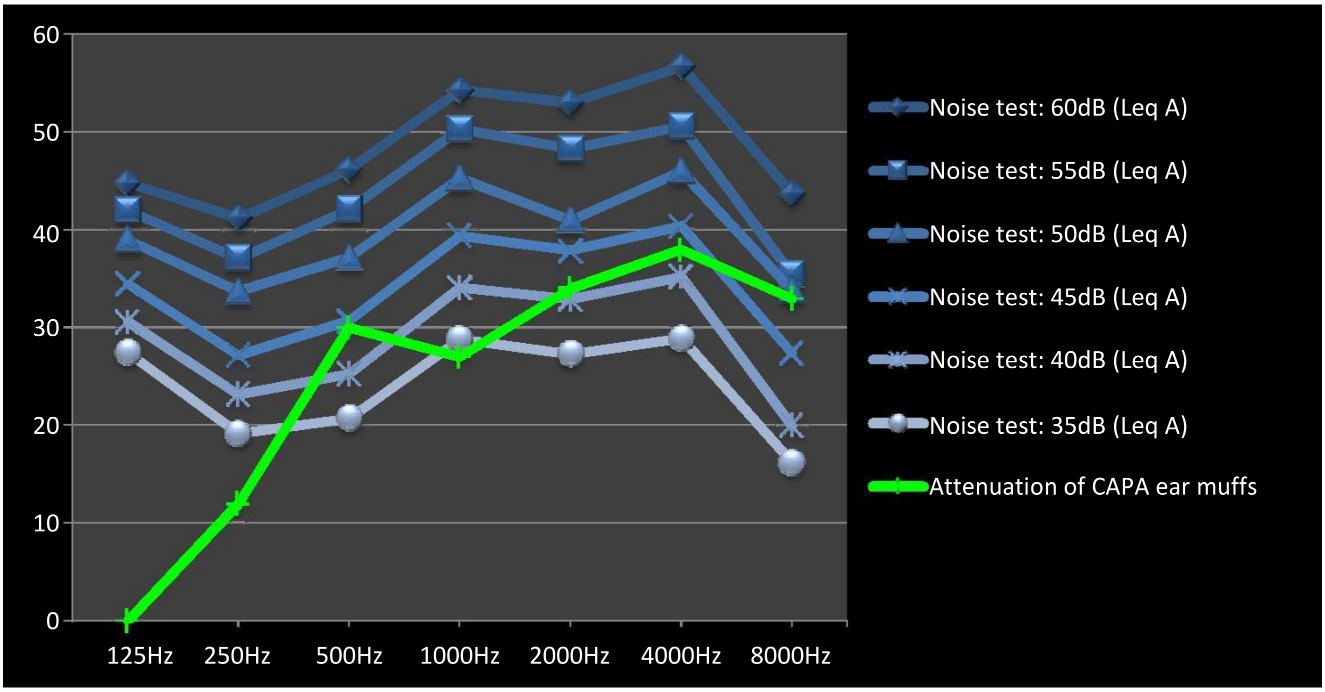


Figure 9: Spectrum of noise used during testing

This is the ambient noise of the acoustic room with added noise (originally white noise), balanced by the amplifier and broadcast on speakers.

These noise measurements were recorded by placing the sound level meter near the subject, according to the diagram below:

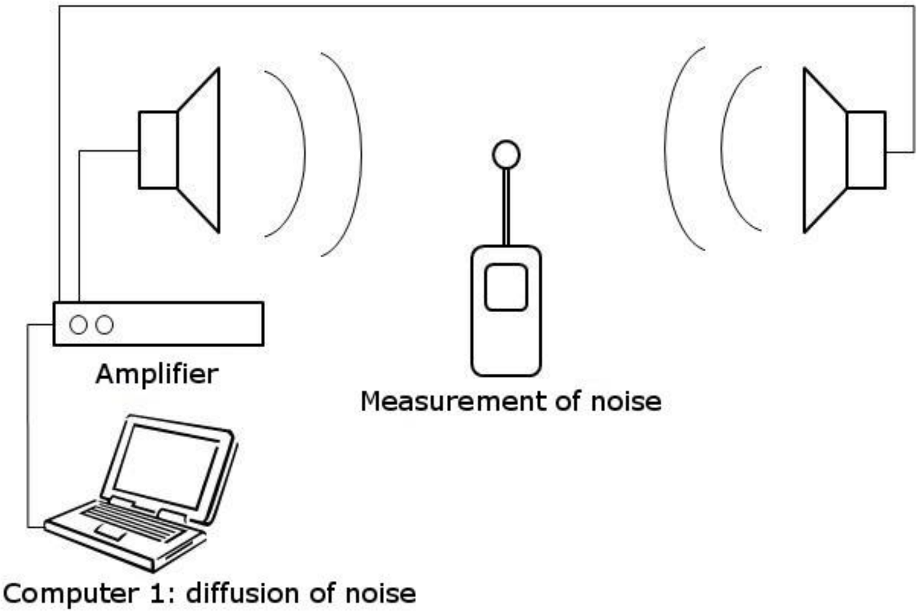


Figure 10: Method for measuring the reference noise

3 Methods and calculations

This section describes the calculation methods used to obtain the results.

3.1 Calculation of the individual reference threshold

For each subject, we have the average hearing thresholds obtained during the study: *Assessment of the repeatability of the CAPA method. This is calculated using 4 CAPA tests over several days.*

In addition, on the test day, we will again measure the hearing thresholds of the subject at normal conditions without artificial noise added.

The average of these data gives us the reference hearing threshold of the subject, at normal conditions.

Example:

Frequency	*125*	*250*	*500*	*1k*	*2k*	*4k*	*8k*
Individual average threshold	37	27	16	10	13	17	33

Frequency	*125*	*250*	*500*	*1k*	*2k*	*4k*	*8k*
D-Day threshold	38	27	16	12	15	20	29

Frequency	*125*	*250*	*500*	*1k*	*2k*	*4k*	*8k*
Reference threshold	38	27	16	11	14	19	31

3.2 Calculating deviations from the normal

During a test, we measure the hearing thresholds of the subject under 6 sounds of different sound intensities (described in paragraph 2.4.3).

The deviation from normal is the difference between the hearing threshold in noise, and the reference threshold in normal conditions.

Example:

Frequency	*125*	*250*	*500*	*1k*	*2k*	*4k*	*8k*
Threshold with noise at 60dB	59	39	29	34	21	25	30
Threshold with noise at 55dB	54	40	27	29	21	22	29
Threshold with noise at 50dB	53	35	22	24	17	20	30
Threshold with noise at 45dB	49	30	18	20	18	18	31
Threshold with noise at 40dB	48	28	18	16	14	17	30
Threshold with noise at 35dB	42	26	16	13	14	16	29
Reference threshold	38	27	16	11	14	19	31

Table 2: Hearing thresholds measured in the presence of noise and reference threshold

Calculating deviations from the normal:

Frequency	*125*	*250*	*500*	*1k*	*2k*	*4k*	*8k*
Deviation with noise at 60dB	22	12	13	23	7	6,5	-1
Deviation with noise at 55dB	17	13	11	18	7	3,5	-2
Deviation with noise at 50dB	16	8	6	13	3	1,5	-1
Deviation with noise at 45dB	12	3	2	9	4	-0,5	0
Deviation with noise at 40dB	11	1	2	5	0	-1,5	-1
Deviation with noise at 35dB	4,5	-1	0	2	0	-2,5	-2

Table 3: Deviation from normal by frequency, depending on the diffused noise in dB

3.3 Representation of deviations from normal

Example:

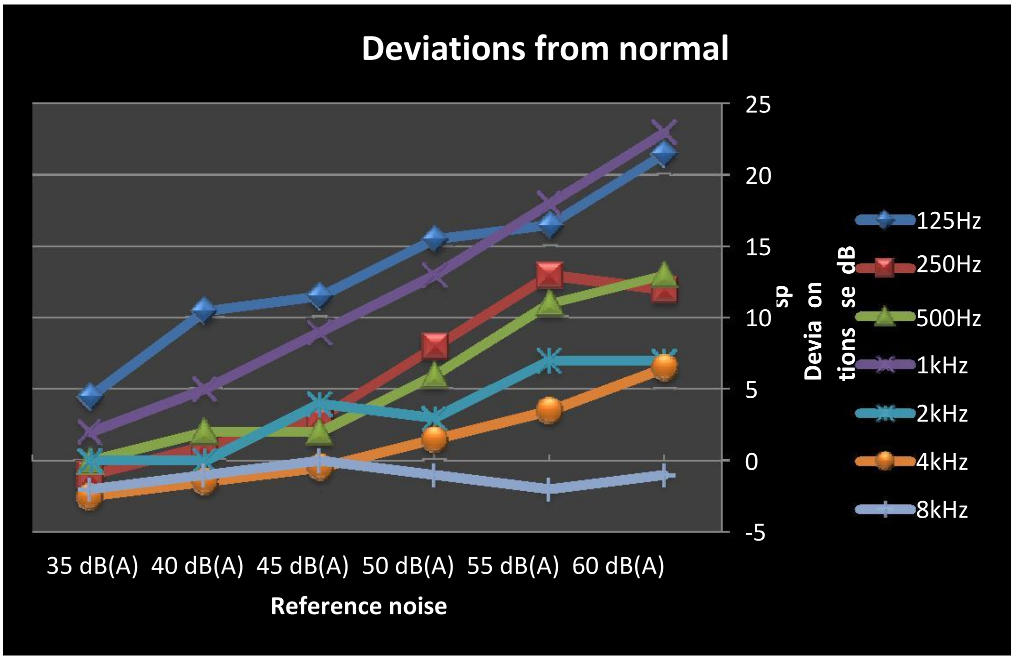


Figure 11: Graphical representation of deviations from normal

3.4 Overall quantification of deviations/differences

To measure the impact of adding artificial noise on the measurements, we must quantify it. We will use an indicator to measure the direct impact on the protection index (PSNA) announced by CAPA.

This PSNA practically follows the same calculation as the SNR. The SNR (Single Number Rating) is the total attenuation coefficient, which is a weighted average of the attenuation at all measured frequencies.

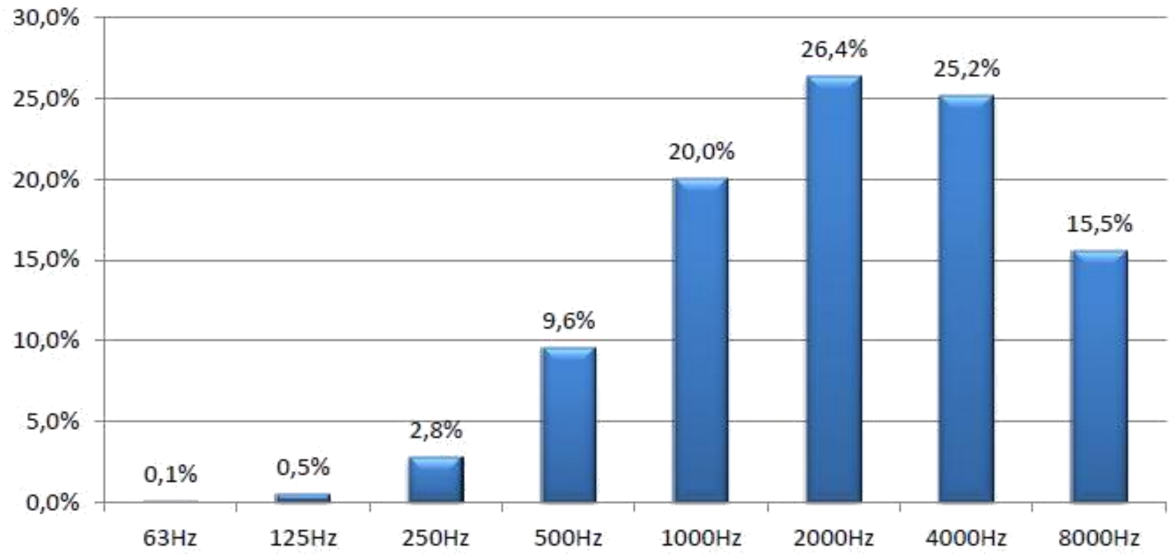


Figure 12: Weighting the SNR depending on the frequencies. The percentage is the weight of each frequency in calculating the SNR.

As we see in the graph above, the weighting of the SNR favors medium and high frequencies. Three frequencies express approximately 70% of the SNR index (1000 Hz, 2000 Hz, and 4000 Hz). It is the same for PSNA.

To measure the impact of differences in the PSNA, we will use the same weighting. For each subject, the weighted deviation from normal is calculated as follows:

$$\textit{Weighted deviation} = 100 - 10\log\sum_{k=1}^{7} 10^{\,0.1(\textit{Lref - Deviation})} - 1{,}5$$

With Lref =

Frequency	125	250	500	1k	2k	4k	8k
Lref	75.4	82.9	88.3	91.5	92.7	92.5	90.4

Example:

Frequency	125	250	500	1k	2k	4k	8k	weighted deviations
Deviation with noise at 60dB	18	16.1	12.3	17.1	6.7	7.8	2.5	7.1
Deviation with noise at 55dB	15.8	13.6	9.2	13.5	4.5	5.4	2	5.4
Deviation with noise at 50dB	12.9	10.2	6.2	9.6	3.1	3.7	1.2	4
Deviation with noise at 45dB	8.9	6.4	2.2	5.8	1.4	1.9	0.8	2.2
Deviation with noise at 40dB	7.9	3.9	0.8	2	0.6	1	0.3	1
Deviation with noise at 35dB	4.3	2.3	0.7	0.9	0.7	0.3	0.4	0.6

Table 4: Differences observed with addition of noise

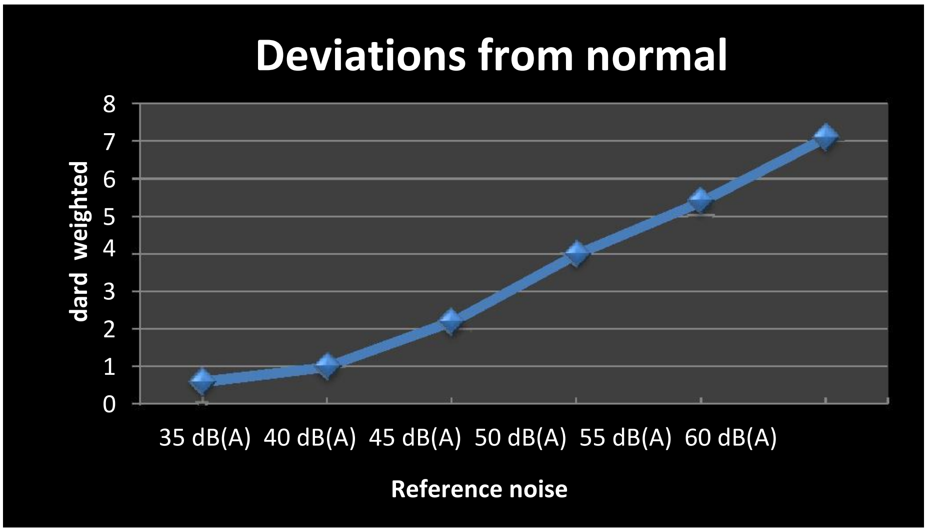


Figure 13: Weighted differences in dB according to ambient noise

This curve can quickly assess the influence of external noise and its impact on the measurement of the hearing threshold without hearing protection, taking into account the weighted SNR (which focuses on medium and high frequencies).

4 Results

With the addition of noise, the subject detects the sound diffused by CAPA at a much higher sound level.

The chart below shows the average of deviations from the reference hearing threshold for each of 12 subjects, across all ears.

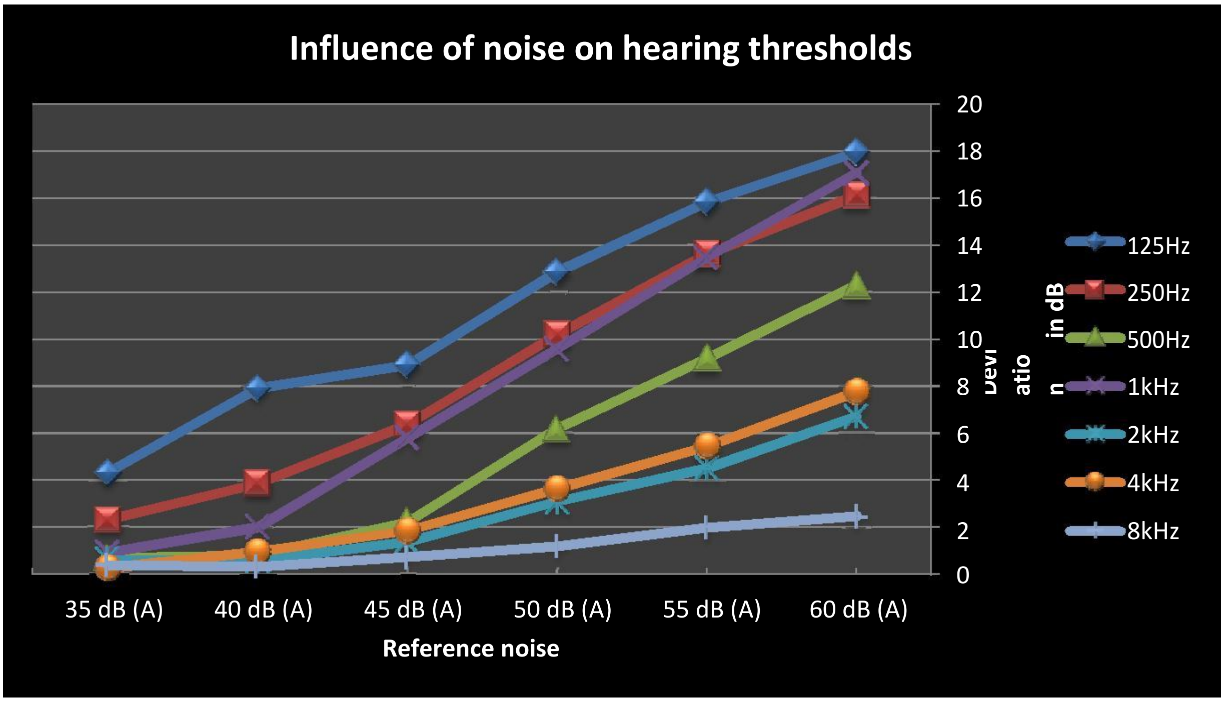


Figure 14: Plotting of deviations observed by frequency

The measurements of high frequencies (2 kHz, 4 kHz and 8 kHz) were the least disturbed by the addition of noise.

Note that the deviations widen around 40 dB (Leq A).

In order to interpret these results, observe the graph showing the difference between the noisy sound environment (given in Section 2.4.3) and the attenuation of the ear muffs (measured in Section 2.3).

Positive values theoretically represent decibels of the external environment that are unfiltered by the ear muffs and heard by the subject.

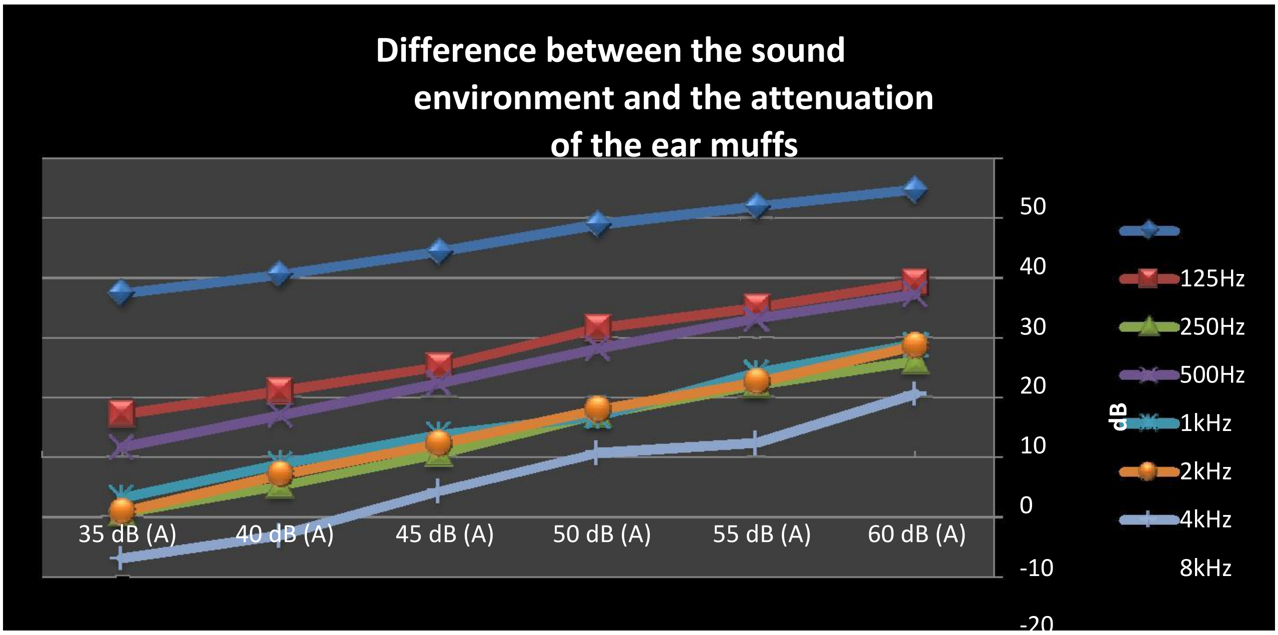
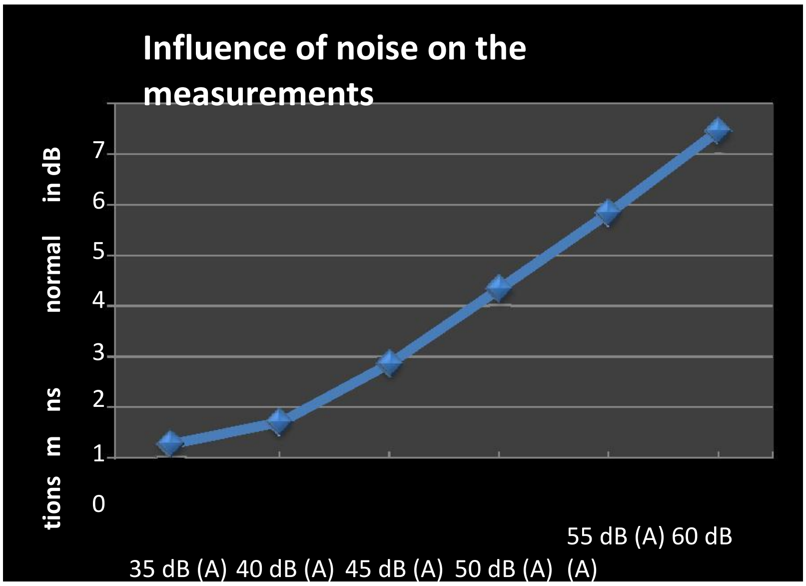


Figure 15: Difference between the sound environment and the attenuation of the ear muffs

We observe that the reaction of the subjects is consistent with these theoretical curves. The most disturbed frequencies (mainly 125 Hz, 250 Hz and 1 kHz) are actually the most present in the sound environment and/or the least attenuated by the ear muffs.



Calculating the weighted average deviation from normal:

This curve can quickly assess the influence of external noise and its impact on the measurement of the hearing threshold without hearing protection, taking into account the weighted SNR (Ref. 3.4).

There is an inflection point at 40 dB (A).

Figure 16: Weighted deviation from the normal based on the noise

For information, compare these results with a noise scale (as per INRS ED 962):

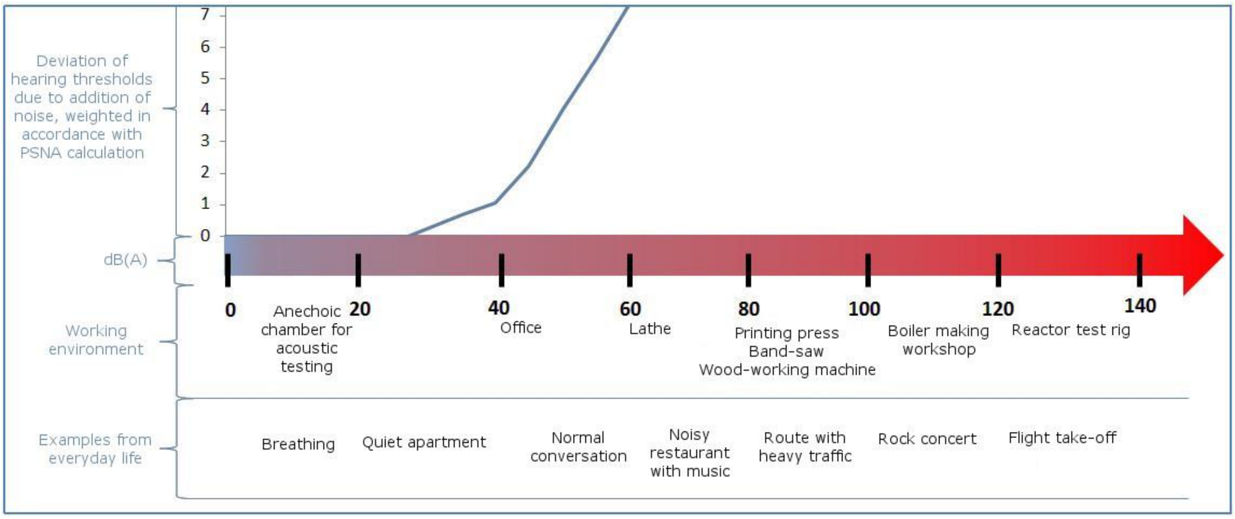


Figure 17: Comparison on a large scale of sound levels (from INRS, ED Study 962)

We have accurately measured the impact of noise on the hearing threshold of the subject. But what is the impact on the PSNA issued by CAPA?

The impact depends directly on the actual attenuation of the hearing protector. Nevertheless, based on the assumption that the CAPA measure with hearing protection is not disturbed by ambient noise (see section 2.1), we can assess the impact on some examples of hearing protectors.

COTRAL Micra XS18

Frequency	125	250	500	1000	2000	4000	8000	PSNA
Theoretical average attenuation (dB)	11	18	21	34	35	40	49	28

We subtract the deviations observed in this study to obtain:

Frequency	125	250	500	1000	2000	4000	8000	PSNA
Theoretical attenuation with noise at 60dB	-7	1.88	8.68	16.9	28.3	32.2	46.5	13.7
Theoretical attenuation with noise at 55dB	-4.8	4.38	11.8	20.5	30.5	34.6	47	16.2
Theoretical attenuation with noise at 50dB	-1.9	7.79	14.8	24.4	31.9	36.4	47.8	19.3
Theoretical attenuation with noise at 45dB	2.08	11.6	18.8	28.2	33.6	38.1	48.3	23
Theoretical attenuation with noise at 40dB	3.08	14.1	20.2	32	34.4	39	48.7	24.4
Theoretical attenuation with noise at 35dB	6.67	15.7	20.3	33.1	34.4	39.7	48.6	26.2

Table 5: Attenuation of the Micra XS18, taking into account the differences of hearing thresholds

COTRAL Micra XS30

Frequency	125	250	500	1000	2000	4000	8000	PSNA
Theoretical average attenuation (dB)	17.9	20.2	25.4	29.6	34.2	38.6	37.2	30

We subtract the deviations observed in this study to obtain:

Frequency	125	250	500	1000	2000	4000	8000	PSNA
Theoretical attenuation with noise at 60dB	-0.1	4.08	13.1	12.5	27.5	30.8	34.7	16.3
Theoretical attenuation with noise at 55dB	2.07	6.58	16.2	16.1	29.7	33.2	35.2	19.1
Theoretical attenuation with noise at 50dB	5.03	9.99	19.2	20	31.1	35	36	22.3
Theoretical attenuation with noise at 45dB	8.98	13.8	23.2	23.8	32.8	36.7	36.5	25.7
Theoretical attenuation with noise at 40dB	9.98	16.3	24.6	27.6	33.6	37.6	36.9	27.5
Theoretical attenuation with noise at 35dB	13.6	17.9	24.7	28.7	33.6	38.3	36.8	28.7

Table 6: Attenuation of the Micra XS30, taking into account the differences of hearing thresholds

COTRAL Micra XSP

Frequency	125	250	500	1000	2000	4000	8000	PSNA
Theoretical average attenuatio n (dB)	28.8	27.6	33.6	33.2	35.3	40.2	40.6	33

We subtract the deviations observed in this study to obtain:

Frequency	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	*PSNA*
Theoretical attenuation with noise at 60dB	10.8	11.5	21.3	16.1	28.6	32.4	38.1	22
Theoretical attenuation with noise at 55dB	13	14	24.4	19.7	30.8	34.8	38.6	24.8
Theoretical attenuation with noise at 50dB	15.9	17.4	27.4	23.6	32.2	36.6	39.4	27.7
Theoretical attenuation with noise at 45dB	19.9	21.2	31.4	27.4	33.9	38.3	39.9	30.3
Theoretical attenuation with noise at 40dB	20.9	23.7	32.8	31.2	34.7	39.2	40.3	31.6
Theoretical attenuation with noise at 35dB	24.5	25.3	32.9	32.3	34.7	39.9	40.2	32.1

Table 7: Attenuation of Micra XSP, taking into account the differences of hearing thresholds

Observe the development of PSNA in the presence of noise:

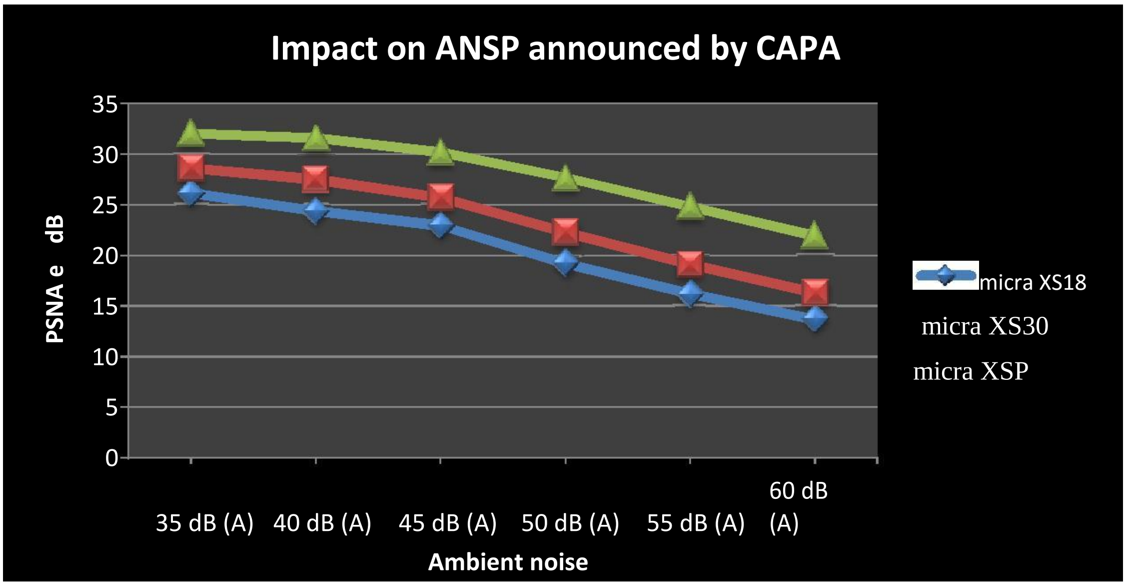


Figure 18: Change in PSNA based on noise

We observe in these three theoretical examples that the impact of environmental noise is indeed real.

Observe the difference between the theoretical attenuation of hearing protectors and the PSNA with noise:

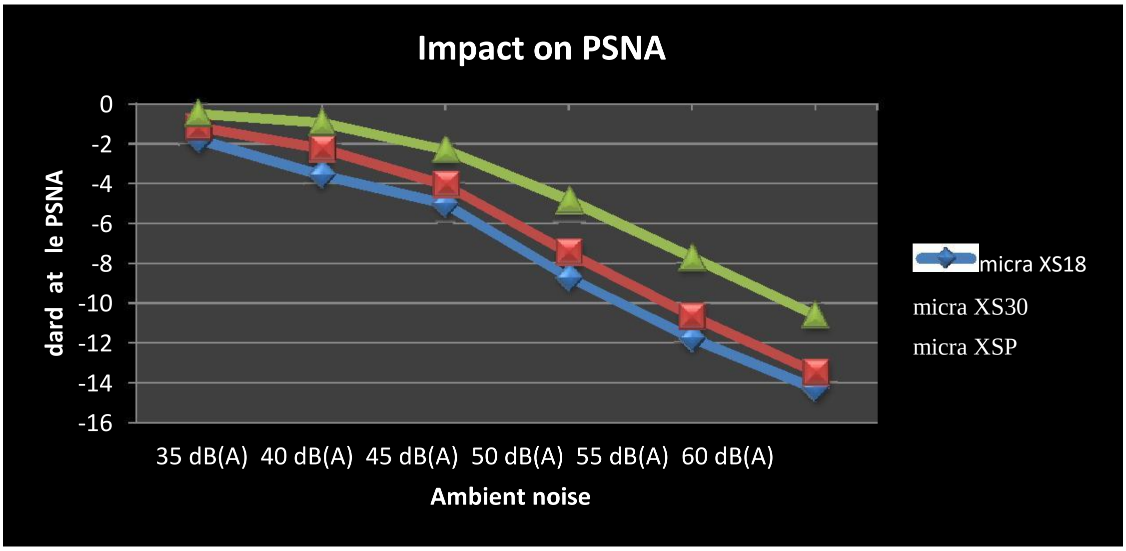


Figure 19: Differences observed in the PSNA based on noise

For a sound of 60 dB (A) (comparable to a nearby rotating machine), the PSNA calculated by CAPA may be underestimated by more than 14 dB.

The slope of the curve increases significantly from 45 dB (A) (Office/normal conversation).

5 Conclusion

The noise level experienced by a subject during a CAPA test deteriorates the results if it exceeds A-weighted 45 decibels. The higher the noise level, the more affected the subject is, and the more the attenuation result deteriorates. Protectors basically having a low attenuation are more impacted. Differences in PSNA can be up to 10 dB between a measurement taken at 40 dB (A) and another taken at 60 dB (A).

The recommendations will attempt to obtain a sound environment not exceeding 40 dB (A) with a limit not exceeding 45 dB (A) during a CAPA test.

6 Appendix: Individual results

__Subject 1:__

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	59	39	29	34	21	25	30
Noise 55	54	40	27	29	21	22	29
Noise 50	53	35	22	24	17	20	30
Noise 45	49	30	18	20	18	18	31
Noise 40	48	28	18	16	14	17	30
Noise 35	42	26	16	13	14	16	29

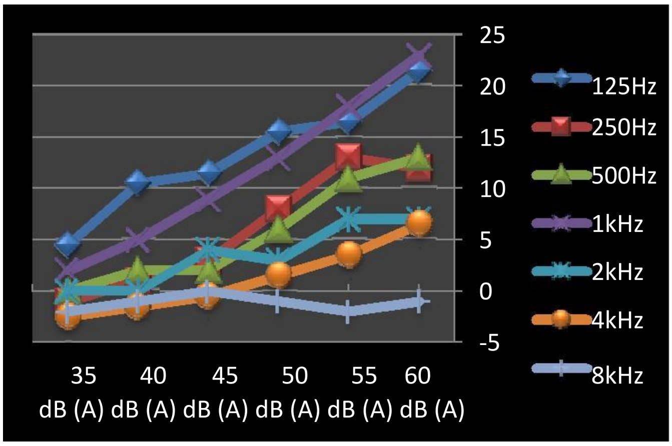
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	38	27	16	11	14	19	31

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	22	12	13	23	7	6.5	-1
Noise 55	17	13	11	18	7	3.5	-2
Noise 50	16	8	6	13	3	1.5	-1
Noise 45	12	3	2	9	4	-0.5	0
Noise 40	11	1	2	5	0	-1.5	-1
Noise 35	4.5	-1	0	2	0	-2.5	-2

Left ear graph:



Deviation from normal by frequency

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	53	37	24	27	24	29	30
Noise 55	51	34	19	23	20	28	31
Noise 50	49	29	19	21	18	26	31
Noise 45	45	26	13	19	17	26	30
Noise 40	41	24	12	16	16	26	30
Noise 35	38	23	11	16	18	28	31

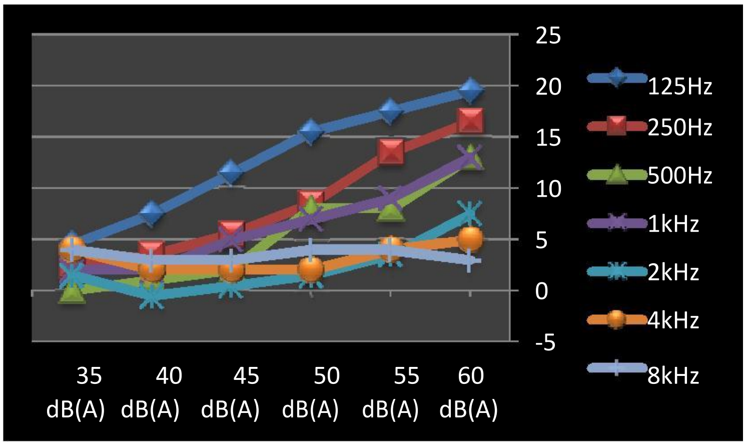
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	34	21	11	14	17	24	27

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	20	17	13	13	7.5	5	3
Noise 55	18	14	8	9	3.5	4	4
Noise 50	16	8.5	8	7	1.5	2	4
Noise 45	12	5.5	2	5	0.5	2	3
Noise 40	7.5	3.5	1	2	-0.5	2	3
Noise 35	4.5	2.5	0	2	1.5	4	4

Right ear graph:



Deviation from normal by frequency

Subject 2

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	52	38	24	30	17	19	19
Noise 55	52	34	18	29	13	16	19
Noise 50	51	27	17	21	11	16	18
Noise 45	45	25	11	14	6	13	18
Noise 40	43	24	10	9	8	11	17
Noise 35	39	21	10	8	7	12	16

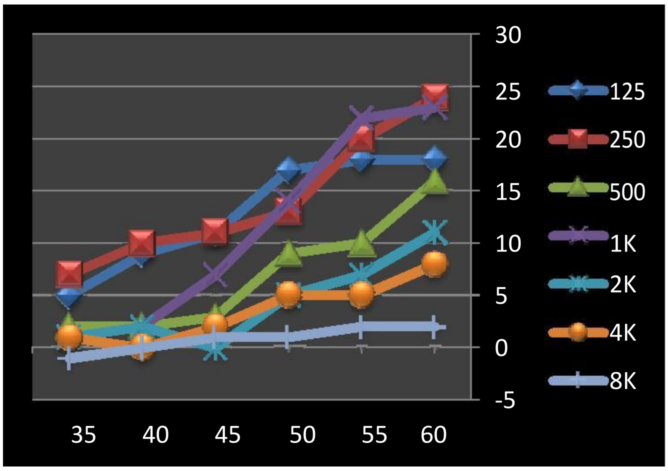
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	34	14	8	7	6	11	17

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	18	24	16	23	11	8	2
Noise 55	18	20	10	22	7	5	2
Noise 50	17	13	9	14	5	5	1
Noise 45	11	11	3	7	0	2	1
Noise 40	9	10	2	2	2	0	0
Noise 35	5	7	2	1	1	1	-1

Left ear graph:



Deviation from normal by frequency

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	54	36	27	28	18	18	21
Noise 55	57	34	25	26	17	16	20
Noise 50	54	31	21	21	9	12	21
Noise 45	49	25	16	16	12	10	20
Noise 40	47	21	12	9	10	10	19
Noise 35	46	20	9	11	9	7	20

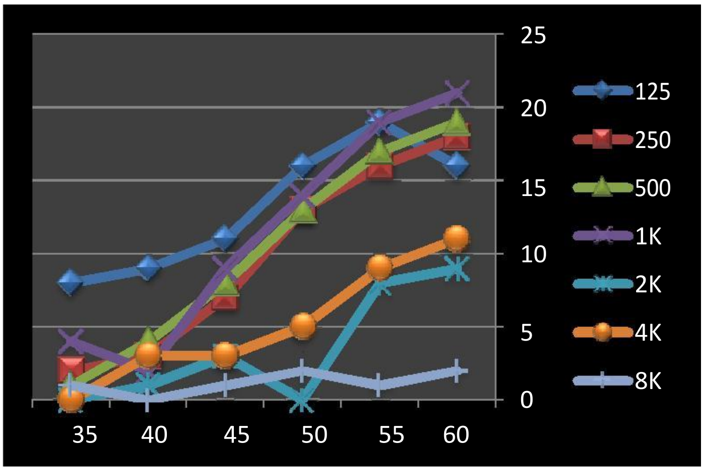
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	38	18	8	7	9	7	19

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	16	18	19	21	9	11	2
Noise 55	19	16	17	19	8	9	1
Noise 50	16	13	13	14	0	5	2
Noise 45	11	7	8	9	3	3	1
Noise 40	9	3	4	2	1	3	0
Noise 35	8	2	1	4	0	0	1

Right ear graph:



Deviation from normal by frequency

Subject 3

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	54	34	26	29	21	29	21
Noise 55	54	33	25	21	19	26	23
Noise 50	52	30	21	22	17	24	21
Noise 45	48	26	17	18	16	22	21
Noise 40	49	24	13	9	13	22	16
Noise 35	42	20	14	8	14	23	16

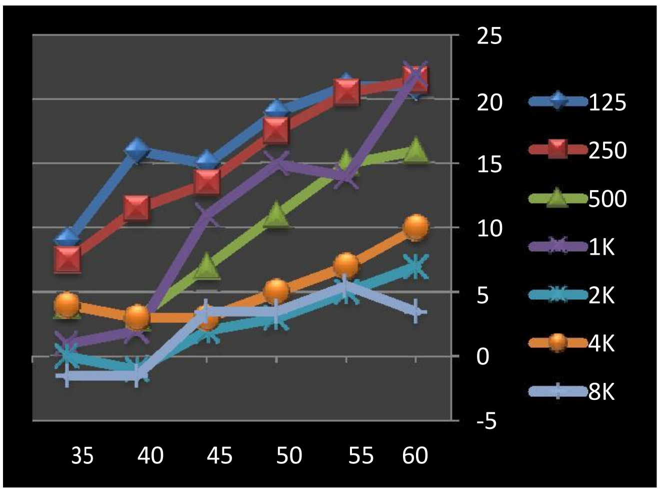
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	33	13	10	7	14	19	18

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	21	22	16	22	7	10	3.5
Noise 55	21	21	15	14	5	7	5.5
Noise 50	19	18	11	15	3	5	3.5
Noise 45	15	14	7	11	2	3	3.5
Noise 40	16	12	3	2	-1	3	-1.5
Noise 35	9	7.5	4	1	0	4	-1.5

Left ear graph:



Deviation from normal by frequency

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	51	28	22	21	21	23	24
Noise 55	46	31	16	18	15	22	24
Noise 50	43	26	13	16	18	20	21
Noise 45	42	23	9	11	16	16	24
Noise 40	39	15	10	8	14	15	22
Noise 35	38	16	11	10	13	15	19

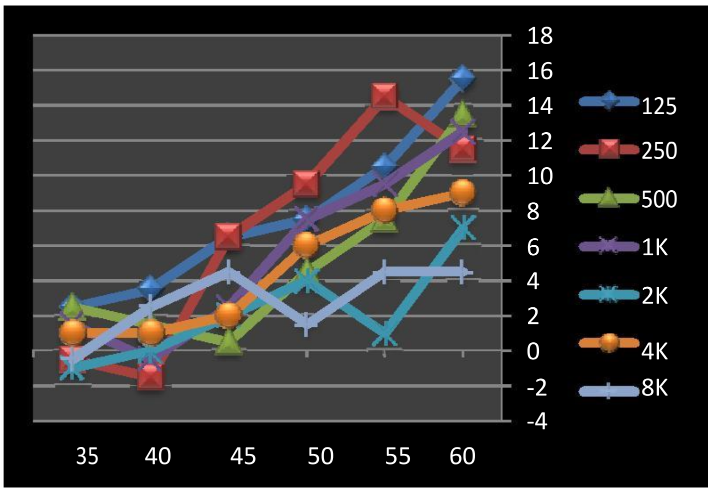
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	36	17	8.5	8.5	14	14	20

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	16	12	14	13	7	9	4.5
Noise 55	11	15	7.5	9.5	1	8	4.5
Noise 50	7.5	9.5	4.5	7.5	4	6	1.5
Noise 45	6.5	6.5	0.5	2.5	2	2	4.5
Noise 40	3.5	-1.5	1.5	-0.5	0	1	2.5
Noise 35	2.5	-0.5	2.5	1.5	-1	1	-0.5

Right ear graph:



Deviation from normal by frequency

Subject 4

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	61	43	30	34	26	25	26
Noise 55	54	38	27	31	24	18	27
Noise 50	55	33	23	23	21	26	22
Noise 45	47	28	20	18	16	15	24
Noise 40	49	27	20	13	15	20	24
Noise 35	38	23	17	11	16	15	22

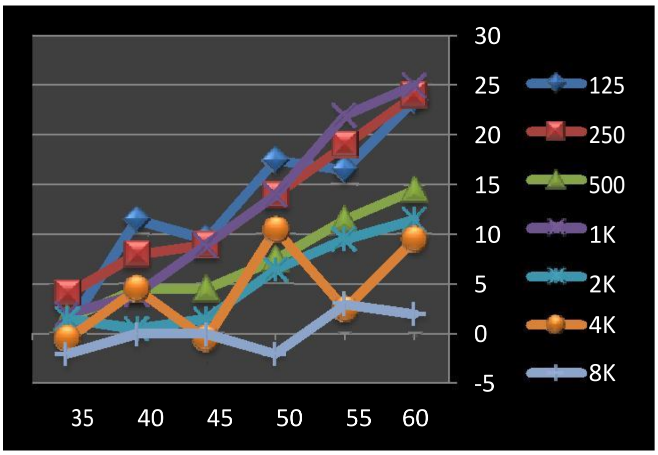
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	34	14	8	7	6	11	17

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	24	24	15	25	12	9.5	2
Noise 55	17	19	12	22	9.5	2.5	3
Noise 50	18	14	7.5	14	6.5	11	-2
Noise 45	9,5	9	4,5	9	1,5	-0,5	0
Noise 40	12	8	4,5	4	0,5	4,5	0
Noise 35	0,5	4	1,5	2	1,5	-0,5	-2

Left ear graph:



Deviation from normal by frequency

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	62	43	37	33	26	26	31
Noise 55	56	37	29	31	23	22	33
Noise 50	58	36	24	24	27	19	29
Noise 45	48	28	19	18	24	17	29
Noise 40	49	26	16	15	20	16	29
Noise 35	48	24	17	21	19	15	31

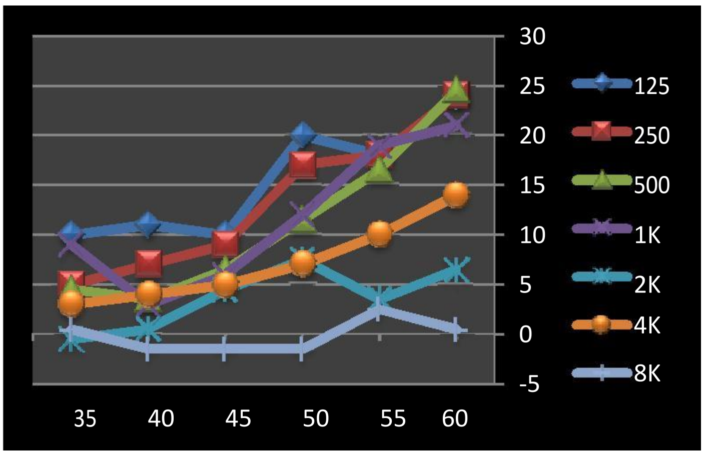
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	52	38	24	30	17	19	19

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	24	24	25	21	6,5	14	0,5
Noise 55	18	18	17	19	3,5	10	2,5
Noise 50	20	17	12	12	7,5	7	-1,5
Noise 45	10	9	6,5	6	4,5	5	-1,5
Noise 40	11	7	3,5	3	0,5	4	-1,5
Noise 35	10	5	4,5	9	-0,5	3	0,5

Right ear graph:



Deviation from normal by frequency

Subject 5

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	58	38	28	31	18	26	39
Noise 55	55	34	29	28	18	23	39
Noise 50	52	30	24	21	13	21	41
Noise 45	45	29	19	23	13	18	40
Noise 40	46	25	19	18	11	18	36
Noise 35	42	22	19	17	13	16	37

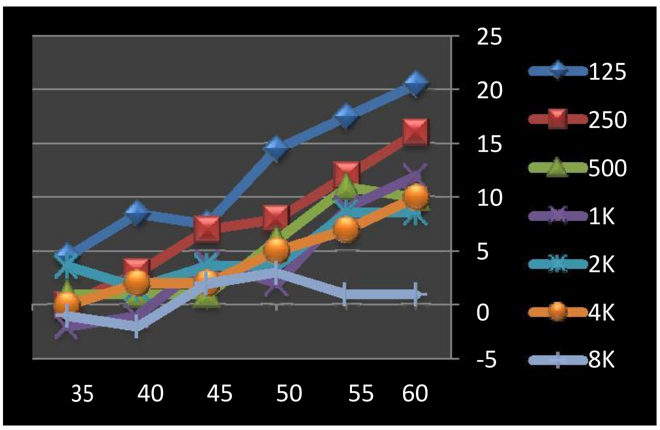
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	38	22	18	19	9.4	16	38

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	21	16	10	12	8.6	10	1
Noise 55	18	12	11	9	8.6	7	1
Noise 50	15	8	6	2	3.6	5	3
Noise 45	7.5	7	1	4	3.6	2	2
Noise 40	8.5	3	1	-1	1.6	2	-2
Noise 35	4.5	0	1	-2	3.6	0	-1

Left ear graph:



Deviation from normal by frequency

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	59	36	26	26	17	32	35
Noise 55	56	36	23	27	18	26	31
Noise 50	50	32	21	23	14	23	33
Noise 45	40	22	17	20	12	19	30
Noise 40	47	26	19	17	12	17	33
Noise 35	42	21	18	14	14	18	33

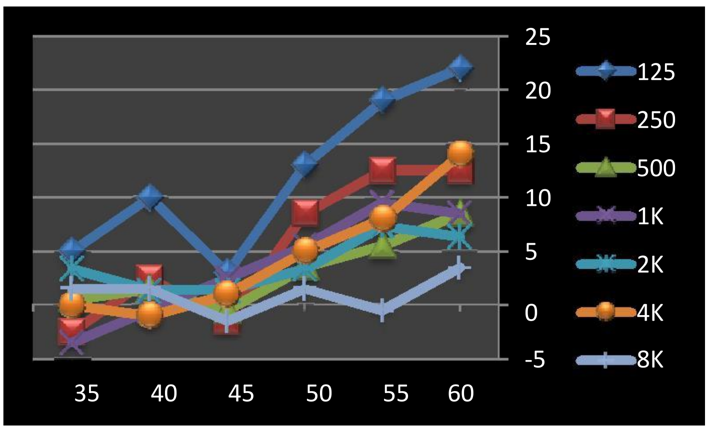
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	37	24	18	18	11	18	32

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	22	13	8.5	8.5	6.4	14	3.5
Noise 55	19	13	5.5	9.5	7.4	8	-0.5
Noise 50	13	8.5	3.5	5.5	3.4	5	1.5
Noise 45	3	-1.5	-0.5	2.5	1.4	1	-1.5
Noise 40	10	2.5	1.5	-0.5	1.4	-1	1.5
Noise 35	5	-2.5	0.5	-3.5	3.4	0	1.5

Right ear graph:



Deviation from normal by frequency

Subject 6

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	51	34	26	30	21	28	27
Noise 55	50	32	22	28	20	29	26
Noise 50	47	29	19	20	18	26	25
Noise 45	44	25	16	19	16	25	26
Noise 40	42	20	13	14	17	25	25
Noise 35	42	22	13	12	17	24	26

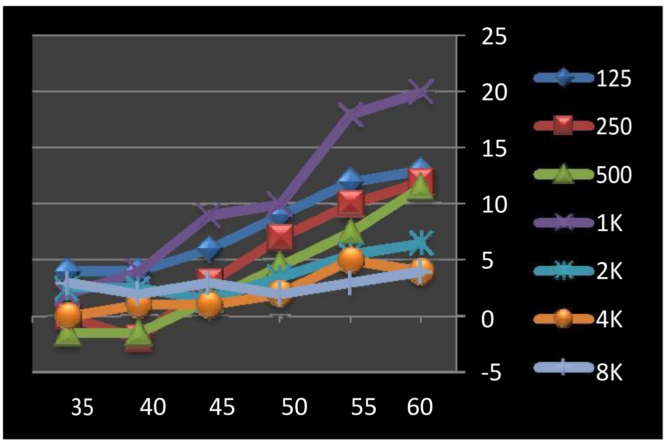
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	38	22	15	10	15	24	23

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	13	12	12	20	6.5	4	4
Noise 55	12	10	7.5	18	5.5	5	3
Noise 50	9	7	4.5	10	3.5	2	2
Noise 45	6	3	1.5	9	1.5	1	3
Noise 40	4	-2	-1.5	4	2.5	1	2
Noise 35	4	0	-1.5	2	2.5	0	3

Left ear graph:



Deviation from normal by frequency

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	49	31	21	28	22	24	23
Noise 55	46	28	22	27	20	17	23
Noise 50	44	25	16	25	19	15	23
Noise 45	43	23	15	18	18	14	21
Noise 40	40	20	12	14	18	13	21
Noise 35	39	19	12	10	18	11	23

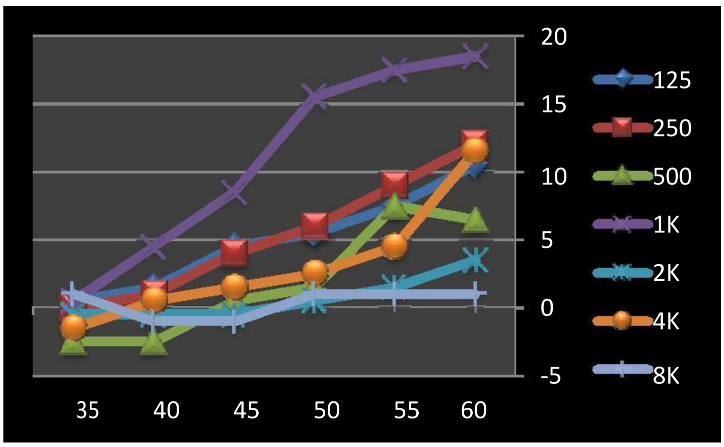
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	39	19	15	9.5	19	13	22

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	11	12	6.5	19	3.5	12	1
Noise 55	7.5	9	7.5	18	1.5	4.5	1
Noise 50	5.5	6	1.5	16	0.5	2.5	1
Noise 45	4.5	4	0.5	8.5	-0.5	1.5	-1
Noise 40	1.5	1	-2.5	4.5	-0.5	0.5	-1
Noise 35	0.5	0	-2.5	0.5	-0.5	-1.5	1

Right ear graph:



Deviation from normal by frequency

Subject 7

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	56	37	25	27	17	23	30
Noise 55	53	36	21	21	11	17	22
Noise 50	48	30	21	20	11	16	22
Noise 45	45	26	16	13	8	14	17
Noise 40	39	24	15	8	6	13	22
Noise 35	40	26	19	13	8	11	26

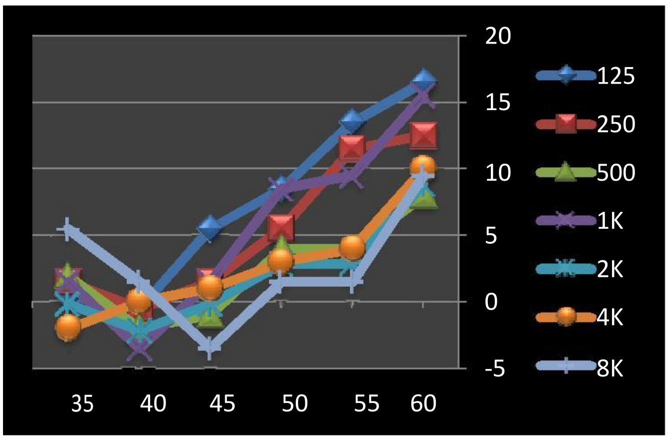
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	40	25	17	12	8.2	13	21

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	17	13	8	16	8.9	10	9.5
Noise 55	14	12	4	9.5	2.9	4	1.5
Noise 50	8.5	5.5	4	8.5	2.9	3	1.5
Noise 45	5.5	1.5	-1	1.5	-0.2	1	-3.5
Noise 40	-0.5	-0.5	-2	-3.5	-2.2	0	1.5
Noise 35	0.5	1.5	2	1.5	-0.2	-2	5.5

Left ear graph:



Deviation from normal by frequency

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	53	35	27	21	16	21	37
Noise 55	51	30	22	16	11	20	39
Noise 50	46	29	21	14	18	16	40
Noise 45	44	26	15	17	12	16	39
Noise 40	38	22	13	11	8	15	38
Noise 35	40	26	12	13	8	16	38

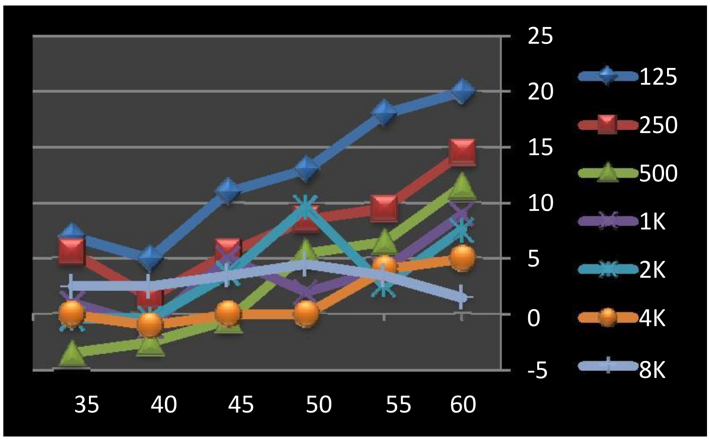
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	33	21	16	12	8.4	16	36

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	20	15	12	9	7.6	5	1.5
Noise 55	18	9.5	6.5	4	2.6	4	3.5
Noise 50	13	8.5	5.5	2	9.6	0	4.5
Noise 45	11	5.5	-0.5	5	3.6	0	3.5
Noise 40	5	1.5	-2.5	-1	-0.4	-1	2.5
Noise 35	7	5.5	-3.5	1	-0.4	0	2.5

Right ear graph:



Deviation from normal by frequency

Subject 8

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	51	34	24	32	16	26	36
Noise 55	52	31	23	23	15	24	34
Noise 50	47	30	18	25	11	24	34
Noise 45	42	24	12	19	10	23	33
Noise 40	38	16	9	17	8	21	33
Noise 35	38	18	11	14	8	19	34

Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	32	13	9.5	11	8.9	23	31

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	20	21	15	22	7.1	3	5
Noise 55	21	18	14	13	6.1	1	3
Noise 50	16	17	8.5	15	2.1	1	3
Noise 45	11	11	2.5	8.5	1.1	0	2
Noise 40	6.5	3	-0.5	6.5	-0.9	-2	2
Noise 35	6.5	5	1.5	3.5	-0.9	-4	3

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	48	33	18	25	16	28	30
Noise 55	49	29	15	19	14	25	29
Noise 50	43	23	12	17	11	23	27
Noise 45	39	20	8	14	9	24	26
Noise 40	36	16	6	11	7	24	25
Noise 35	32	14	8	6	8	23	25

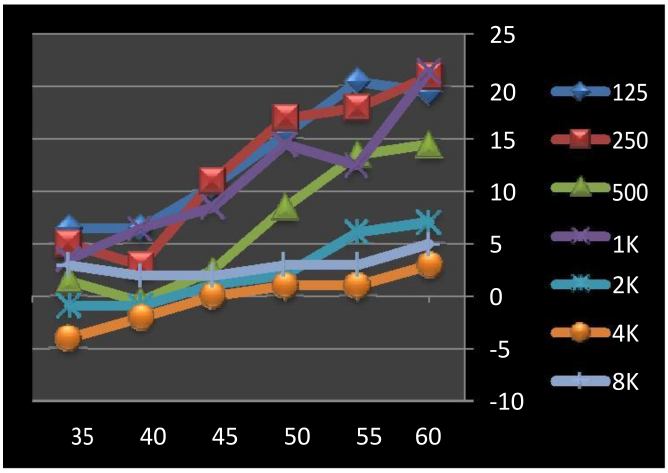
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	29	15	7.8	8	9	24	27

Deviations observed:

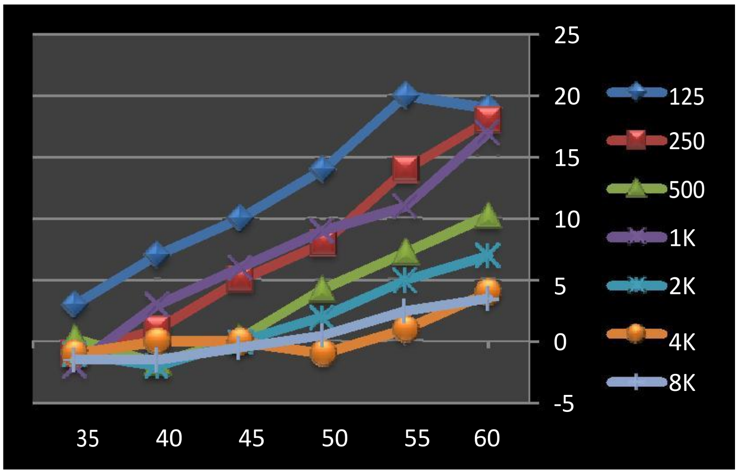
Freq.	125	250	500	1000	2000	4000	8000
Noise 60	19	18	10	17	7	4	3.5
Noise 55	20	14	7.3	11	5	1	2.5
Noise 50	14	8	4.3	9	2	-1	0.5
Noise 45	10	5	0.3	6	0	0	-0.5
Noise 40	7	1	-1.8	3	-2	0	-1.5
Noise 35	3	-1	0.3	-2	-1	-1	-1.5

Left ear graph:



Deviation from normal by frequency

Right ear graph:



Deviation from normal by frequency

Subject 9

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	59	41	25	29	25	21	27
Noise 55	56	39	22	28	21	18	24
Noise 50	49	33	19	21	22	14	23
Noise 45	50	30	17	20	18	12	22
Noise 40	48	28	12	19	16	8	22
Noise 35	43	24	12	17	16	6	21

Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	34	23	13	18	16	6.9	20

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	25	19	13	11	9.5	14	7.5
Noise 55	22	17	9.5	10	5.5	11	4.5
Noise 50	15	11	6.5	3	6.5	7.1	3.5
Noise 45	16	7.5	4.5	2	2.5	5.1	2.5
Noise 40	14	5.5	-0.5	1	0.5	1.1	2.5
Noise 35	9	1.5	-0.5	-1	0.5	-0.9	1.5

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	54	34	26	33	22	26	20
Noise 55	48	32	21	29	17	22	19
Noise 50	47	30	19	24	16	19	19
Noise 45	43	28	16	16	16	16	18
Noise 40	41	25	14	12	14	14	16
Noise 35	35	25	15	10	12	11	15

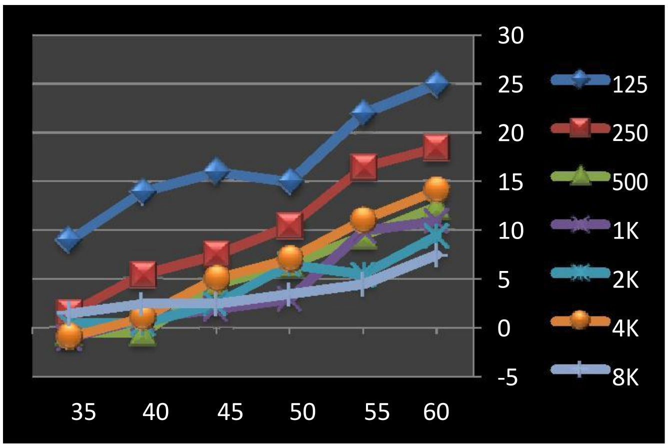
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	34	22	14	11	12	13	17

Deviations observed:

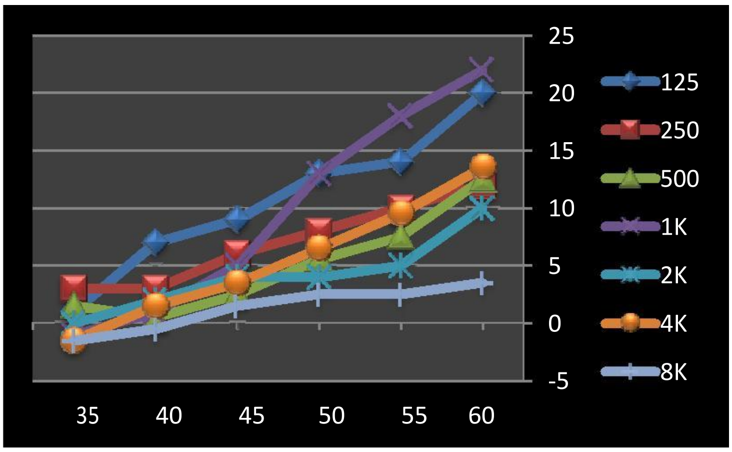
Freq.	125	250	500	1000	2000	4000	8000
Noise 60	20	12	13	22	10	14	3.5
Noise 55	14	10	7.5	18	5	9.5	2.5
Noise 50	13	8	5.5	13	4	6.5	2.5
Noise 45	9	6	2.5	5	4	3.5	1.5
Noise 40	7	3	0.5	1	2	1.5	-0.5
Noise 35	1	3	1.5	-1	0	-1.5	-1.5

Left ear graph:



Deviation from normal by frequency

Right ear graph:



Deviation from normal by frequency

Subject 10

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	56	31	21	34	17	34	53
Noise 55	49	27	16	25	16	31	54
Noise 50	46	27	13	24	11	31	53
Noise 45	43	19	8	17	13	31	53
Noise 40	43	21	11	9	13	29	53
Noise 35	39	16	9	7	13	27	49

Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	37	17	9.5	7.4	12	30	52

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	19	15	12	27	5	4.5	1.5
Noise 55	12	11	6.5	18	4	1.5	2.5
Noise 50	9	11	3.5	17	-1	1.5	1.5
Noise 45	6	2.5	-1.5	9.6	1	1.5	1.5
Noise 40	6	4.5	1.5	1.6	1	-0.5	1.5
Noise 35	2	-0.5	-0.5	-0.4	1	-2.5	-2.5

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	50	29	20	28	13	39	39
Noise 55	49	28	17	23	14	40	41
Noise 50	43	20	15	24	14	41	42
Noise 45	42	19	11	15	14	40	42
Noise 40	45	20	9	14	13	38	41
Noise 35	34	15	8	9	13	36	44

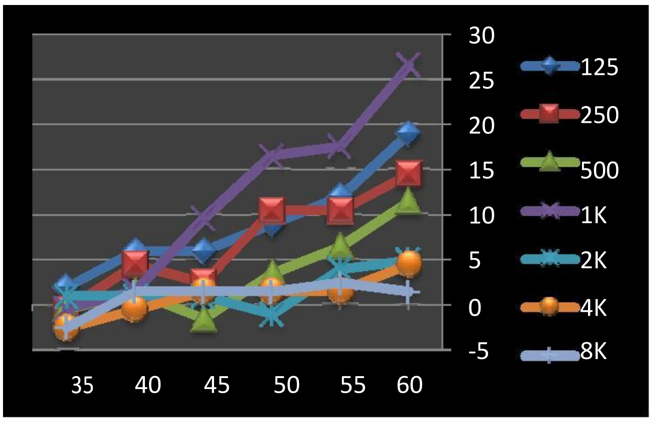
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	34	13	7.7	8.2	14	37	47

Deviations observed:

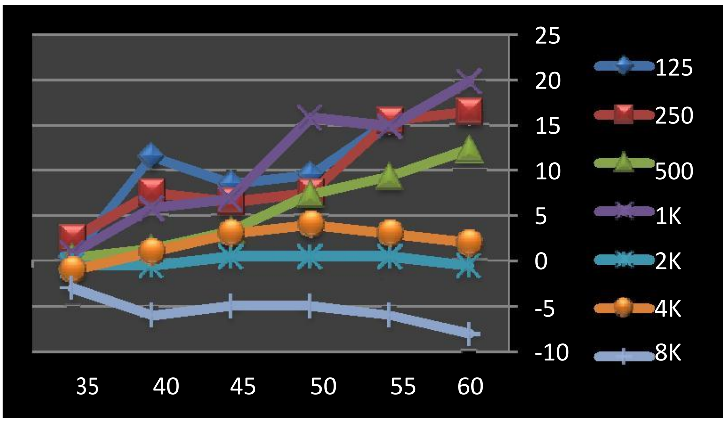
Freq.	125	250	500	1000	2000	4000	8000
Noise 60	17	17	12	20	-0.5	2	-8
Noise 55	16	16	9.4	15	0.5	3	-6
Noise 50	9.5	7.5	7.4	16	0.5	4	-5
Noise 45	8.5	6.5	3.4	6.9	0.5	3	-5
Noise 40	12	7.5	1.4	5.9	-0.5	1	-6
Noise 35	0.5	2.5	0.4	0.9	-0.5	-1	-3

Left ear graph:



Deviation from normal by frequency

Right ear graph:



Deviation from normal by frequency

Subject 11

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	56	37	25	25	16	19	26
Noise 55	53	34	21	22	13	21	25
Noise 50	55	35	20	19	13	13	24
Noise 45	48	29	15	16	11	11	28
Noise 40	50	26	16	14	11	11	26
Noise 35	46	24	15	12	9	12	25

Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	40	23	15	11	8.9	10	25

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	16	15	10	14	7.1	9	1.5
Noise 55	13	12	6	11	4.1	11	0.5
Noise 50	15	13	5	8	4.1	3	-0.5
Noise 45	8	6.5	0	5	2.1	1	3.5
Noise 40	10	3.5	1	3	2.1	1	1.5
Noise 35	6	1.5	0	1	0.1	2	0.5

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	56	32	26	26	15	19	28
Noise 55	56	33	26	23	14	19	29
Noise 50	54	31	28	18	12	17	28
Noise 45	49	28	21	17	10	14	25
Noise 40	53	26	22	16	11	16	28
Noise 35	46	24	21	14	10	21	26

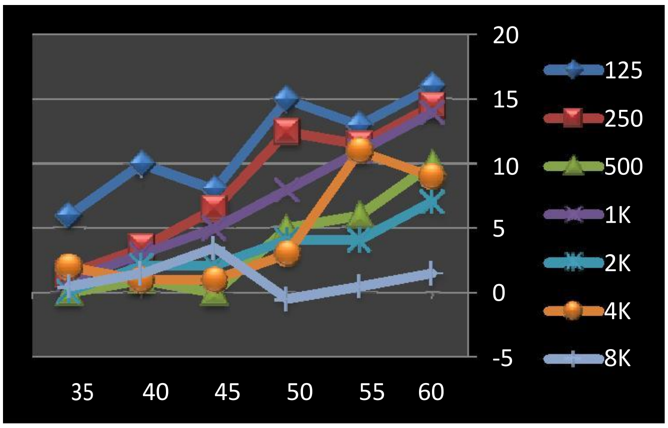
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	44	20	19	14	10	13	26

Deviations observed:

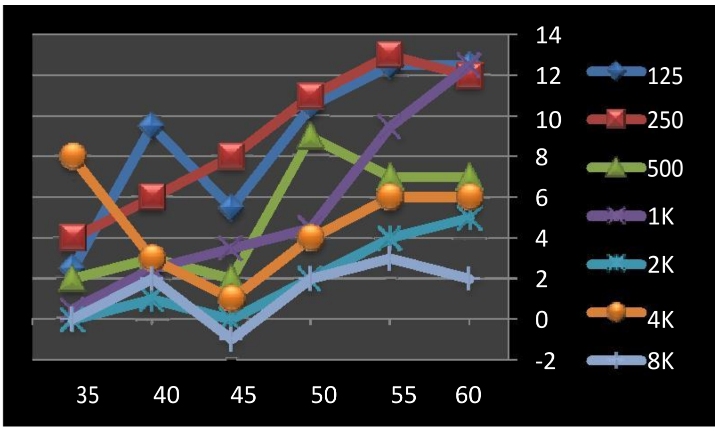
Freq.	125	250	500	1000	2000	4000	8000
Noise 60	13	12	7	13	5	6	2
Noise 55	13	13	7	9.5	4	6	3
Noise 50	11	11	9	4.5	2	4	2
Noise 45	5.5	8	2	3.5	0	1	-1
Noise 40	9.5	6	3	2.5	1	3	2
Noise 35	2.5	4	2	0.5	0	8	0

Left ear graph:



Deviation from normal by frequency

Right ear graph:



Deviation from normal by frequency

Subject 12

Left ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	45	33	22	26	15	37	44
Noise 55	52	31	21	24	17	39	43
Noise 50	48	30	13	15	15	38	40
Noise 45	46	26	14	15	10	40	39
Noise 40	43	24	11	11	15	36	40
Noise 35	43	25	12	11	14	37	42

Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Ref.	37	19	12	12	12	38	39

Deviations observed:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	8	15	11	14	3.5	-0.5	5.5
Noise 55	15	13	9.5	12	5.5	1.5	4.5
Noise 50	11	12	1.5	3	3.5	0.5	1.5
Noise 45	9	7.5	2.5	3	-1.5	2.5	0.5
Noise 40	6	5.5	-0.5	-1	3.5	-1.5	1.5
Noise 35	6	6.5	0.5	-1	2.5	-0.5	3.5

Right ear

Hearing thresholds measured:

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	52	33	22	26	16	32	41
Noise 55	49	25	19	25	12	32	41
Noise 50	43	23	15	21	13	30	39
Noise 45	46	27	16	19	13	33	39
Noise 40	44	24	13	21	19	31	39
Noise 35	40	21	13	18	19	30	39

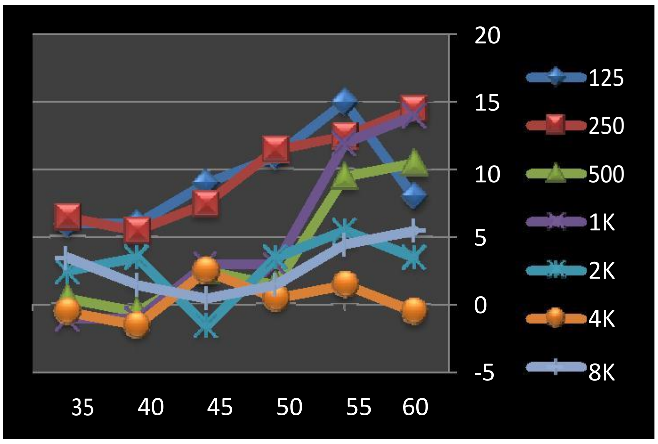
Reference measurement (without noise):

Freq.	125	250	500	1000	2000	4000	8000
Noise 60	38	19	13	18	16	29	40

Deviations observed:

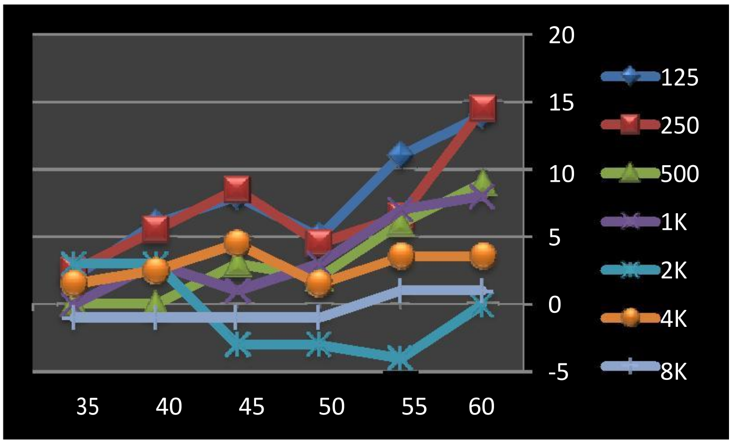
Freq.	125	250	500	1000	2000	4000	8000
Noise 60	14	15	9	8	0	3.5	1
Noise 55	11	6.5	6	7	-4	3.5	1
Noise 50	5	4.5	2	3	-3	1.5	-1
Noise 45	8	8.5	3	1	-3	4.5	-1
Noise 40	6	5.5	0	3	3	2.5	-1
Noise 35	2	2.5	0	0	3	1.5	-1

Left ear graph:



Deviation from normal by frequency

Right ear graph:



Deviation from normal by frequency