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*Ann-Cathrine Lindblad, Åke Olofsson,
Björn Hagerman, Ulf Rosenhall*

KAROLINSKA INSTITUTET
Dept. of Clinical Neuroscience
Unit of Technical Audiology

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ABSTRACT

In military services the noise levels are often extreme. In ordinary shooting training in the Swedish Armed Forces, however, the risk to get a permanent, noise induced hearing loss is very small, provided the safety measures are enforced. The question has been raised that urban combat training performed indoors in bunker-like rooms because of reflections might involve an increased risk, at least for the most susceptible individuals. To deal with that question hearing tests were performed on 23 officers before and after a shooting session in a bunker-like room. (Results reported in TA135). We found some temporary effects on hearing (highly significant for our own PMTF-method see further down) but also some results that needed clarification. It was desirable to repeat the experiments with an extended test schedule.

Another interesting question is whether antioxidants might reduce the effects of noise on human hearing like it can do for animals. This is an important aspect for the military. Therefore in the second experiment a few tablets of N-acetylcysteine, NAC, were administered after the shooting. Thus it could serve as a pilot test on the effect of antioxidants. Now 11 officers were tested, 6 of whom had participated in the earlier test.

The function of the outer hair cells and their control system were measured with transient evoked otoacoustic emissions, TEOAEs, with and without contralateral noise, and by measuring thresholds for brief tones in modulated noise, psychoacoustical modulation transfer function, PMTF. Very accurate tone thresholds were measured by Békésy-technique.

Since the effects on hearing thresholds in the first experiment were small, substantial and widely accepted proof of the efficacy of the NAC treatment was not to be expected. Still, there are some results on threshold behaviour supporting the use of NAC treatment. But more conclusive: There were significant differences between noNAC- and wNAC-results both regarding PMTF and TEOAEs. The PMTF-results are clear and logical, but the uncertainty regarding the interpretation of the TEOAE-results actually increased.

In new experiments it would be preferable with an exposure that had more impact on conventional hearing thresholds, but PMTF measurements would still have the largest potential to prove the effect of NAC or other treatments.

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contact: Per-Anders Hellström

Mailing address	*Visiting address*	*Phones*	*Fax*	*Org.nr:*
Teknisk audiologi, KI	Danderyd hospital area	+46-8 544 966 36, direct	+46-8 544 966 44	01 202100 2973 01
Blå vägen, hus 15	Blå vägen, house 15	+46-8 544 966 30, general	***E-Mail***	***VAT-No.:***
S-182 30 DANDERYD	DANDERYD	+46-8 544 966 31, secr	anncat.lindblad@cns.ki.se	SE202100297301
SWEDEN	SWEDEN		***Home page:*** http:// www.cns.ki.se	

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INTRODUCTION

Excessive exposure to noise is the most common cause of hearing loss, tinnitus and hyperacusis. Moreover, noise induced hearing loss (NIHL) is one of the most common causes of occupational health problems, both in the civil working sector and in the military defence, in spite of great efforts to reduce health hazards caused by excessive noise exposure. Tinnitus is common in the population, about 14% have tinnitus often or always, 40% have tinnitus of any type, continuous as well as occasional. Noise exposure is the cause of the problem for between 20% - 40% of them.

In military services the noise levels are often of an extreme character. In the ordinary shooting training within the ordinary training program in the Armed Forces, however, the risk for military personnel to get permanent NIHL is very small, provided that the safety instructions are enforced. Nevertheless there can be some doubts if hearing protectors provide enough attenuation for all subjects in some situations. One of the most pronounced exposures to noise occurs during shooting in urban combat training. These training sessions are performed indoors in bunker-like rooms. The acoustical properties of these spaces are extremely poor. Silent intervals are filled in by reflections of the sound by the concrete walls, and the noise levels are enhanced. The Health Authorities of the Swedish Armed Forces are concerned that urban shooting training might involve increased risk for NIHL. Occult, non-symptomatic, transitory influence of hearing function may occur, perhaps quite often. Such occult hearing dysfunction can be detected with modern auditory tests.

The possibility of using antioxidants to reduce the effect of noise on human hearing should be rather intriguing for the military. It has been shown in animals that antioxidants can decrease the effect of noise. With sensitive, modern auditory tests an evaluation on humans might be performed without risking damaging exposure.

Hearing thresholds and other auditory tests were performed before and after shooting in urban combat training in two connected studies carried out in close co-operation with the Swedish Armed Forces (contact: Per-Anders Hellström). In the second study, involving 11 officers, the subjects were treated with N-acetylcysteine, NAC, after the shooting (the wNAC-experiment). The results were compared with those of the 23 officers that had earlier gone through the same procedure with shooting and hearing measurements but without NAC treatment (noNAC). The safety instructions (including the use of hearing protectors) imposed by the Swedish Armed Forces were applied.

The NAC evaluation has to be regarded as a pilot study only. The opportunity was taken to test NAC at the same time, when there was a need to do a follow-up of the first study to try to clarify some results. Thus the format of the NAC evaluation is somewhat lopsided.

METHOD

Test conditions

Two rounds of ammunition, with 20 shots in each, were fired from an automatic gun, Ksp-58, in a bunker used for urban combat training. Two people were in the bunker at the same time – the right-handed shot and a companion placed close by on his/her right side.That means that they had the weapon between them. Both were wearing their standard active hearing protectors. The shooting took place on four (noNAC) plus two (wNAC) separate days with time for hearing tests on the days before and after. Each day of shooting three times two people were exposed. Hearing tests were performed with three measuring systems in a house about 100 m from the bunker on the day before, on the day of shooting, and when considered necessary to monitor effects of the exposure the day after or still later. Originally, in noNAC, no measurements were planned after the day of shooting. The results for most subjects indicated otherwise and later measurements were performed when possible. In wNAC such test occasions were scheduled from the beginning. The test subjects were instructed to avoid noise exposure 24 h before the test.

The test setup with three measuring systems allowed performing hearing tests on three people at a time. The time schedule was adjusted to that. The test parameters for each type of test were chosen to make it possible to start new measurements every 15 minutes. The test subjects were numbered consecutively. Subjects with odd numbers were shots, those with the even numbers immediately after were their respective companions. The hearing tests just after the shooting were performed at the same time for both subjects in a pair. The odd numbered subjects performed all the other hearing tests 15 minutes earlier in relation to the shooting than the even numbered ones. The test schedules for one day in noNAC and one day in wNAC are shown in tables in the appendix.

In the noNAC-experiment an engineer group from FMV's test site at Karlsborg registered sound pressure levels at a reference microphone placed on a stand at a certain distance from the weapon in the bunker, in the left ear canals and in the shots right ear canal by three miniature microphones. The maximum sound pressure levels were 164 – 166 dB SPL at the reference microphone and 135 – 154 dB SPL in the ear canal under the hearing protectors. The variation in these levels did not show any significant relation to the results in the hearing tests. They are not further reported here.

Test schedule

1) The afternoon before the shooting training (tone thresholds on both ears, i.e. audiogram; TEOAEs on both ears and PMTF left ear). Test occasion, **df** (the **d**ay be**f**ore.
2) The same morning as the shooting, 75-45 min or 60-30 min before the shooting (TEOAEs on left ear, audiogram. In wNAC also PMTF left ear.). Test occasion **m0**.
3) Directly after the shooting (2 audiograms). On the last shooting day of noNAC the second of these audiograms was replaced by a PMTF-measurement. Test occasions **m1** and **m2**.
4) 1 hour after shooting (audiogram). Test occasion **m3**.
5) 2 hours after shooting (audiogram). Test occasion **m4**.
6) 3 hours after shooting (audiogram; TEOAEs and PMTF on left ear). Test occasion **m5**.
7) Those who showed results considered worse than their preexposure results at 3 hours after shooting were tested again the day after shooting (if possible). That regards the audiogram and the PMTF-measurements. Test occasion **nd (n**ext **d**ay**).** Evaluation of the possible changes in otoacoustic emissions is more time-consuming. It was not possible to check that too after the measurements had come to an end on the shooting days. In wNAC all types of measurements were performed again next day.

8) If in noNAC the inspection of results in 7) implied so, further measurements were performed a few days later. In wNAC everyone was tested again about one week after shooting. Test occasion **nv** (next week = “**n**ästa **v**ecka”)

Medication

The NAC treatment consisted of Acetylcysteine Tika, 200 mg. One tablet was taken dissolved in half a glass of water directly after exposure, one hour later, at breakfast the day after, and one hour later. That means immediately before test occasions m1 and m3 and before nd, although with unequal time before test occasion nd depending on what time they were scheduled for measurements.

Test subjects

Officers in the Swedish Army served as test subjects. The age of the 23 test subjects in noNAC ranged from 22 to 50, median 29, mean 31, s.d. 7 years. Two of the officers were women.
An attempt was made to get those subjects in noNAC who had shown effects of the noise exposure and were good test subjects, to participate in wNAC. It was possible to include five such subjects. A sixth subject did not turn up so the officer in charge took his place. He is a very good test subject but the effects of exposure on him are small. So: in wNAC there was 11 subject of whom 6 participated in both experiments. The subjects in wNAC were younger: range 21 to 37 years of age, median 26, mean 27 and s.d. 4 years.

Hearing tests

1. Tone thresholds with fixed frequency Békésy technique - audiogram

Tone thresholds for left and right ears separately were measured with pure tones (i.e. sinusoids) at 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz.

A pulsating tone is presented. The duration is 275 ms, including attack- and release times, and with a 175 ms long interval between pulses. The level of the tone is increased by 2.8 dB/s until the subject detects the tone and starts pressing the button. The level of the tone decreases with the same speed until the button is released again, etc. Thus a zigzag is formed around the threshold level. The turning-points are registered by the computer. The measurement is concluded after 10 turning points. The first two turning points are not used in the calculation. The threshold is calculated as the mean value of the medians of the remaining upper and lower turning points. The threshold is presented with a resolution of 1 dB. The method gives better accuracy than conventional audiometri with 5-dB-steps between stimulus levels.

2. Psychoacoustical modulation transfer function (PMTF)

The threshold of a brief tone, 4 ms, is measured in a fluctuating noise. Separate thresholds are measured with the tone at the peaks and in the valleys of the noise. The measurements were performed on the left ear at 4000 Hz, with a modulation frequency of 10 Hz and at the levels 35 to 85 dB SPL. The threshold of the brief tone was also measured without noise.

The PMTF-test reflects the ability of an ear to follow the natural, slow intensity modulation of speech. This modulation is caused by syllables, words and intonation. A poor ear has an increased difficulty to detect for example soft sounds after loud sounds.

The thresholds were determined with the same Békésy-technique as described earlier. Seven noise levels have been used: 25 to 95 dB SPL (sound pressure level re $2*10^{-5}$ Pa) in steps of 10 dB. The noise consisted of the octave-bands around the test tone frequency 4000 Hz with a sinusoidal 100 % intensity-modulation of 10 Hz. To prevent listening to sounds outside the octave-band, a masking noise is added. It consists of a faint, periodic broadband noise. The degree of accuracy is about 2 dB for peak and valley thresholds, as well as for their difference. Further details about the method can be found in Lindblad et al. (1992). Experiments with quinine, which causes a transitory hearing loss, have shown that PMTF is a sensitive test of the function of the outer hair cells. Thus PMTF-measurements have proved valuable for testing high quality hearing, as required for example from sonar operators.

The principal difference between normal-hearing and sensorineurally hearing-impaired ears is shown in Figure 1.

When plotting the thresholds relative to the noise level as a function of level of the modulated noise you find that normal-hearing subjects have a maximum around 55 dB SPL on the peak-threshold-curve and on an about 10 dB higher noise level on the valley-threshold-curve (green curves). A sensorineural hearing loss decreases the height of the maxima and moves them towards higher sound pressure levels, Lindblad et al. (1993) (red curves). Note that the shape of the curve is the most important feature, not the individual data points. The values at the local maxima of the peak- and valley-threshold curves have been used in statistical analyses and so have the respective noise levels (x-values) of these maxima.

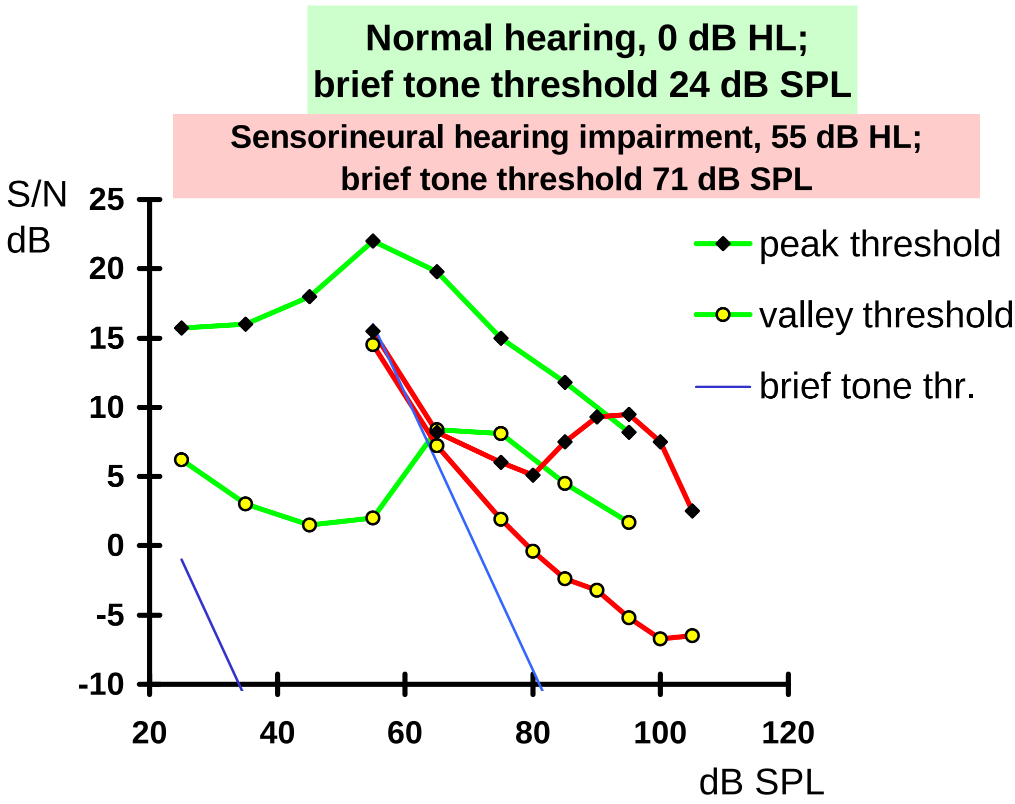

Figure 1. PMTF-peak and valley thresholds for one normal-hearing and one sensorineurally impaired subject.

In our research about susceptibility to noise induced hearing loss we have found that conscripts with basically continuous noise exposure develop like towards a sensori-neural hearing loss. Those who have been subjected to incidents with shooting with unprotected ears – with impulse noise of not too extreme levels – develop in a contrary way. An example is shown in Figure 2, which shows the results of a conscript at the beginning of military service and at the end, and who happened to be in the garage when a blank shot went off. The maxima, both on the peak-threshold-curve and the valley-threshold curve, move towards 45 dB SPL – and they become extremely high. Note the need of en extended scale in the figure! We interpret this as an effect of slackening of the efferent control of still quite vigorous outer haircells. The small differences between peak- and valley-thresholds at all noise levels might cause reduced speech recognition ability. These early indicators of damage to the cochlea are described in Lindblad & Köbler (2002, in Swedish).

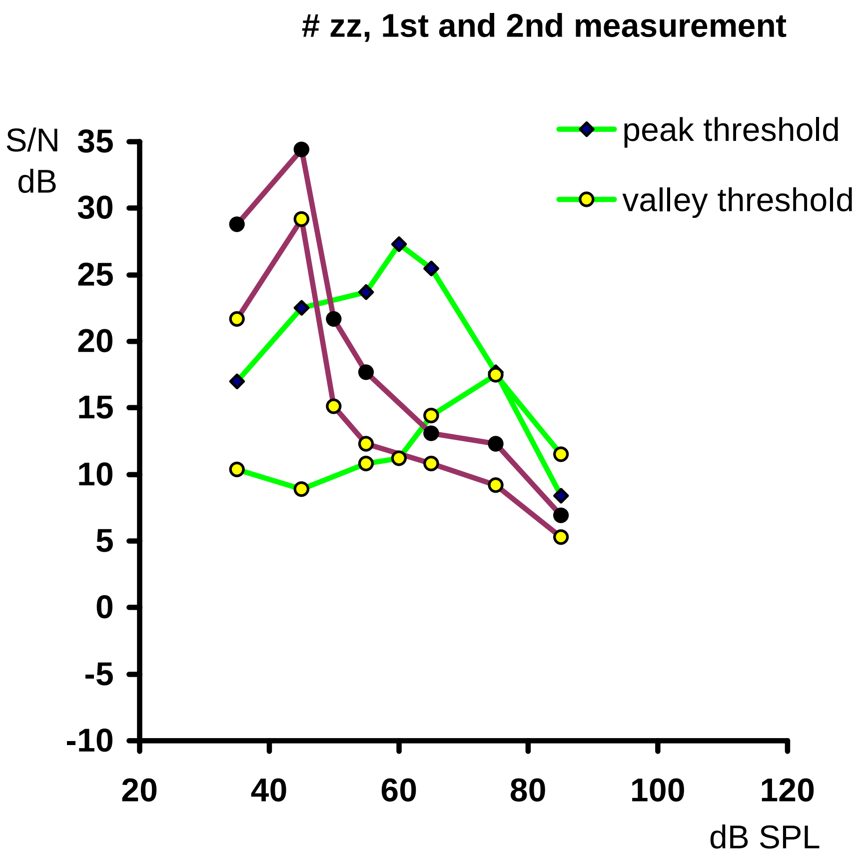

Figure 2. "Hyper-PMF". Peak and valley thresholds before and sometime after a shooting incident.

3. Transient Evoked Otoacoustic Emissions, TEOAEs

A reasonably well functioning ear emits sound when stimulated by sound. The emissions are not merely acoustical reflections but also results of active processes in the cochlea. This has been known for about 20 years, and can now be used for measuring the functioning of an ear. A probe placed in the ear canal is used to send a stimulus into the ear, and to measure the resulting emissions from the ear. The responses to brief stimuli, e.g. clicks, are called TEOAEs (transient evoked acoustic emissions). To test the function of efferent system controlling the outer hair cells a contralateral noise can be applied. Also spontaneous emissions, SOAEs, are emitted from approximately 50% of all normal ears without stimulation. We attempted to measure them in noNAC but we found that the test set-up, with three test equipments and several people in the same room, gave too many disturbances for reliable SOAEmeasurements. The software used for these measurements is developed at Technical Audiology. The obtained resolution is higher than that of commercial equipment.

Clicks with the duration of 80 µs are repeated with a frequency of 50 Hz. The measurement was performed in a non-linear mode to enhance those components in the response, which have a non-linear dependence of the stimulus level, and to suppress the linear components. To accomplish this the polarity of every fourth click is reversed and the sound pressure level is increased by a factor of 3. The acoustical responses from 1000 clicks are averaged, after removal of the primary click by windowing-technique. The stimulus level is specified as so called peak equivalent sound pressure level. TEOAEs at 75 and 85 dB peSPL with and without contralateral masking consisting of 70 dB broadband noise were used in noNAC, in wNAC only 85 dB peSPL. The RMS-value for the broadband response (the response that is correlated to the clicks), over the interval of measurement, is used as a variable in the analyses as well as in 1000 Hz-bands. Also the uncorrelated response is analysed in 1000 Hz-bands. For further details see Cheng (1993).

In our noise susceptibility project (Lindblad & Köbler, 2002) the same type of effects as for the PMTF-results appeared for the TEOAEs. Those who were subjected to the continuous noise showed decreasing TEOAEs like going towards a sensorineural hearing loss, whilst those exposed to strong, but not extremely strong, impulse sounds showed stronger TEOAE responses and intensified chaotic activity which might mean still vigorous outer hair cells with less efferent control

Equipment

Three almost identical test systems were used. Each of them consisted of a Tucker-Davis Technologies (System II) module system including signal processor DSP32C, AD/DA-converter and computer controlled amplifiers and attenuators. The TDT-systems were controlled by personal computers. Circumaural earphones, Sennheiser HD 200, were used for the psychoacoustical measurements. Only one of the systems was used for measuring otoacoustic emissions. The probe system used for that was of type ER-10C from Etymotic Research.

Statistical analyses

Some of the statistical analyses were performed with Microsoft Excel to make it possible to study individual graphs of the time functions of the large amounts of result parameters without a too overwhelming amount of work. Some t-tests between results before and after exposure were also performed. For ANOVAs and factor analyses Statgraphics Plus for Windows 2.1 was used.

RESULTS

Tone thresholds

The time course of the tone thresholds averaged over subjects and over the frequencies 2 - 8 kHz are presented in Figure 3. A few data in the figure are striking. One is that the wNAC group had better hearing thresholds than the noNAC group at most test occasions. This effect might be attributed to more years of exposure, since there are more officers in the noNAC group that have passed 30 years of age.
There seems to be an overnight recovery effect (from df to m0) giving better hearing thresholds in the morning, but it is not significant (p=0.19). Thresholds in the afternoon three hours after shooting, m5, are basically the same as in the afternoon before shooting, df. That raises questions about the suitability of using hearing thresholds when the effects of exposure are of the same order as the daily variations. The subjects´ right ears give an impression of having slightly better thresholds than their left ears before noise exposure (occasions df and m0). That effect, however, is not at all significant.
The noNAC group´s right (best) ears have a marked bounce effect culminating at m2 about 20 to 30 minutes after the noise exposure (df to m2 is significant , p=0.019). This bounce is gone again at m3 one hour after the exposure. The bounce effect is present at all tested frequencies, see Figure A1, in Appendix. Interestingly enough the first NAC tablet, taken just before m1, can not possible have influenced the results until some time during the m2 measurements.
ANOVAs (over NAC, frequency and ear) for each test occasion, mx-m0, show that the effect of NAC on the threshold change from just before exposure is significant all day, p<0.0012, except that it is not at all significant at m3 were the bounce effect on the right ear in noNAC is most pronounced.

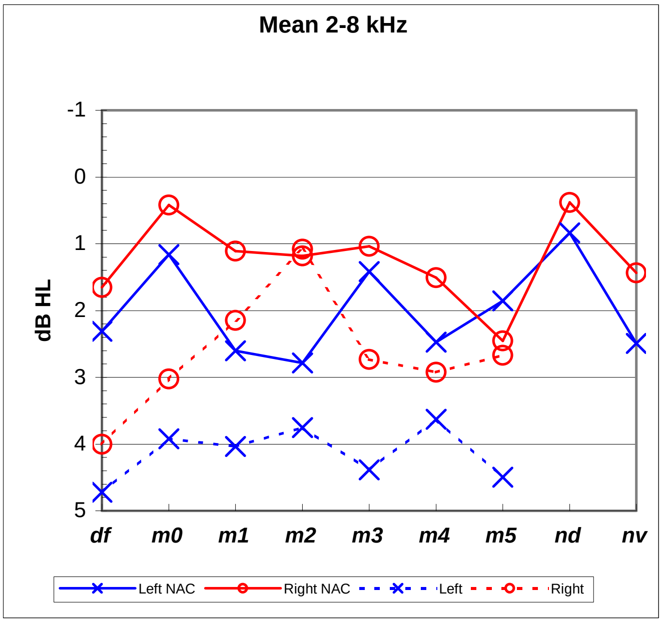

Figure 3. Tone thresholds averaged over subjects and over the frequencies 2-8 kHz for the group without NAC (N=23, dashed lines) and the group treated with NAC (N=11, solid lines). Test occasion on the x-axis. (In noNAC a couple of data points are omitted since the subject was obviously falling asleep.)

In noNAC, the largest threshold changes for the group three hours after exposure, at m5, occurred at 4 and 6 kHz and thresholds were only 1.2 dB worse than just before exposure, at m0, with p-values p=0.055 and p=0.09 respectively. The size of the changes were in the order of the daily variations. But we also noticed the variations in thresholds over time, including the bounce effect. As an indicator of these fluctuations, both towards worse and better thresholds, we therefore calculated the ***standard deviation (and variance) for each subject and frequency over the six measurements from test occasions m0 to m5***. Standard deviations for repeated thresholds measured with conventional audiometry and the headphone used, Sennheiser HDA 200, (at Rosenhall´s clinic) are shown in Figure 4 below. The standard deviations of the earphone show the same general frequency dependence as the s.d. for the right ear but our absolute values are slightly lower since of our Békésymethod has higher accuracy. Note that the s.d.s are definitely higher at 8 kHz, where the placing of the earphones is most crucial. For the left ear, however, the s.d.s in noNAC were higher than for the right ear at 1 - 6 kHz. A test of equal variances showed that the variances were significantly different at 3 and 4 kHz, $p<0.05$ ($F_{97.5}$, d.f.=22) but not at 6 kHz.. This speaks in favour of the conclusion that there was a temporary effect of the exposure without NAC after all.

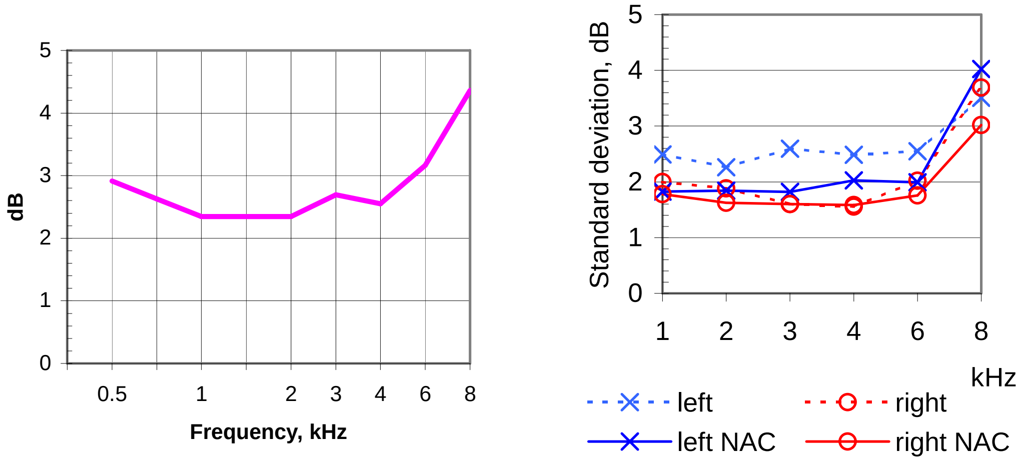

Figure 4. Left: Standard deviations of earphone Sennheiser HDA 200 at conventional audiometry. Right: “Means” of subjects’ individual standard deviations over the six measurements m0-m5, for the group without NAC (N=23, dashed lines) and the group treated with NAC (N=11, solid lines).

Also with NAC the left ear seems to be more influenced by the noise exposure than the right ear. But for the right ear the s.d.s are the same as in noNAC except at 8 kHz. Unfortunately an ANOVA calculated for the variances showed no significant effect of NAC (p=0.38), although a t-test for the left ear only showed an almost significant effect, p=0.06 (one-sided test, unequal variance). It is nowadays known that the left ear is more vulnerable than the right.That argument speak in favour of true effects of exposure which are reduced by NAC.

PMTF

The generally most worth-while way of analysing the PMTF-results is to use the thresholds at the maxima of the peak- and valley-curves and the noise levels at which these maxima occur. In this investigation, with fairly subtle effects on hearing and measurements and with as large steps as 10 dB in noise level, it is not worth analysing the noise levels, the x-values of the peaks. However, the maximum peak- and valley-thresholds show interesting results.

One complication about extracting the maxima that is worth mentioning is that the measured threshold relative to the noise (the S/N in the figure) at low noise levels can be a reflection of a high threshold in quiet for the brief tone rather than an effect of the modulated noise.

Because of that, the threshold value expressed in S/N, especially for the valley threshold, can be higher in this area than at the local maximum of the curve that is caused by the non-linearity of the cochlea. In noNAC a few subjects have thresholds for the brief tone that give the highest valley threshold values at 35 and/or 45 dB SPL. Therefore visual readings were made, although for a couple of subjects the valley maximum reading is uncertain.

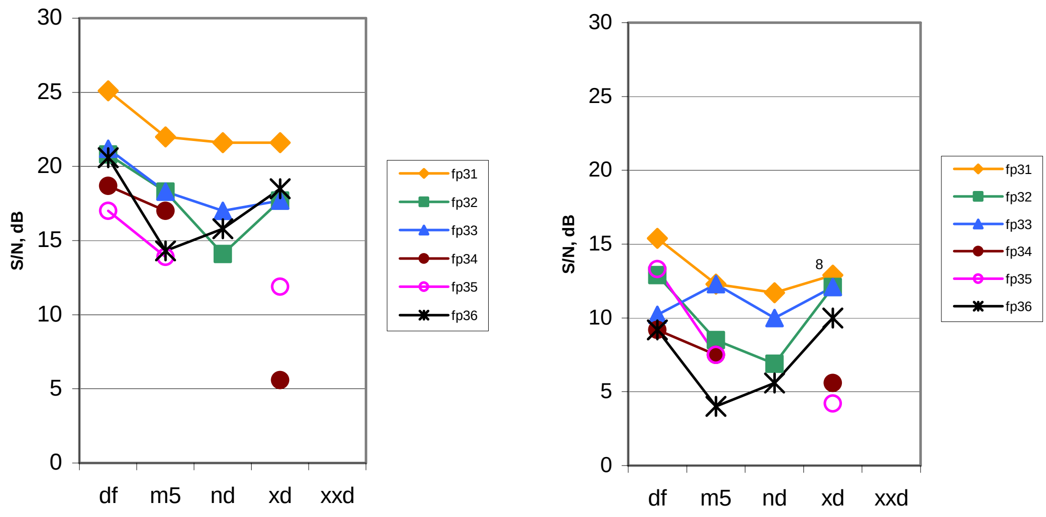

Figure 5. Examples of PMTF peak and valley maximum values over time; 6 subjects in the noNAC group. Left: peak thresholds. Right: valley thresholds.

A look at the individual results **in noNAC** (Figure 5) revealed that for most subjects the maxima were obviously decreasing between the day before, df, and three hours after exposure, m5. These changes were highly significant for the group ($p \ll 0{,}001$) both for peak and valley-thresholds. With further measurements the days after the exposure the maximum thresholds started to recover for some subjects but not for all, and in a couple of cases further noise exposure was an obvious reason. **The direction of the changes was mainly like the long term effect caused by continuous noise, towards a sensorineural hearing loss**.

Figure 6 shows average results of the PMTF measurements in both noNAC and wNAC, which were all made on the left ear. Clear decreases of the maximum peak thresholds are seen from the day before, df, as well as from wNAC´s added measurement in the morning, m0, to the result at the end of the shooting day, m5. However, this effect is more accentuated in noNAC. A two-sided t-test was performed to **compare the changes in mean values at the occasions df and m5 in**

noNAC and wNAC. **The change in maximum peak threshold was significantly different (larger for noNAC than for wNAC) (p==.009). The change in maximum valley threshold was significantly different in noNAC and wNAC when using a one sided t-test (p=0.003)**. That should suffice as proof since we know the direction of changes, with decreasing maxima, from noNAC. It can also be noted that **in noNAC both peak and valley thresholds were even more affected on the next day, nd. In wNAC they did not change much after m5**. The change(df to nd) in maximum peak threshold differs significantly between noNAC and wNAC, p=0.006, and so does the change in maximum valley threshold, p=0.013.

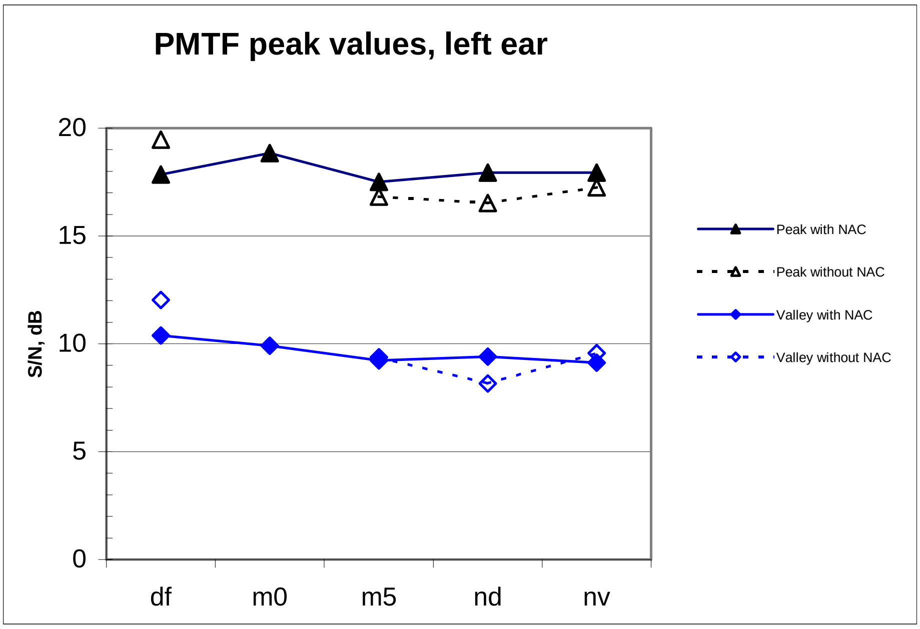

Figure 6. PMTF-results. Mean of maximum peak thresholds and mean of maximum valley thresholds on the left ear for the noNAC group (N=23) and for the wNAC group (N=11). Test occasions on the x-axis. (S.d.s were 3 - 5 dB.)

TEOAEs

Results of TEOAE measurements are shown in Figure A2 in the Appendix for the total response (only for the correlated response), and for three different frequency areas, 0-2.5 kHz, 2.4-4.5 kHz, and 4.5-8 kHz. An ANOVA was performed for the *difference* values between measurements at test occasions m0 and m5. Main factors were NAC (with or without), noise (with or without contralateral noise), and response type (correlated or uncorrelated response). This was done for the three frequency areas separately. For the lowest and highest frequency areas, 0-2.5 kHz and 5.5-8 kHz, no factors or interactions were significant. For the most exposed frequency area 2.5-4.5 kHz, the factor NAC was highly significant (p=0.003).

Since there are significant effects of NAC on the TEOAEs one might feel satisfied. However, one might wonder why the activity of the OHC increases more with NAC than without. In our noise susceptibility project we found hyperactivity after shooting. Is it possibly so that NAC further decreases the control of the OHC? Compare with the figures of suppression! There seems to be a lot of chaotic, uncorrelated, activity going on at m5 in wNAC. The suppression of the total correlated signal is negative at m0 and m5 although the three bands actually have suppression. That must mean that the activity below 500 Hz increases a lot, has negative suppression, at these occasions. A look at the prints from some subjects tells that this does not happen to everybody, but is very pronounced for some people. But why is the suppression bad already at m0, before shooting? And why are the morning values in wNAC generally worse than in the afternoon before? One might think that the haircells would be more rested in the morning like in noNAC.

(To test the fluctuations of the TEOAEs during a day without exposure we measured on three people in the lab at 10 a.m., 2 p.m. and 4.30 p.m. The 60 year old with a slight hearing loss had his highest TEOAEs in the morning, but the two normal-hearing women, 25 and 60 years old, had markedly higher values in the afternoon. Stimulus levels were checked not to have caused that. The noNAC and wNAC group mainly differed in hearing in the same way as the man and the women here. However the small number of people in our lab test gives no proof.)

After noNAC we wondered that the effects of shooting on TEOAEs were smaller than those of resting over night. Unfortunately the TEOAE measurements in wNAC seems rather to have added to our confusion.

DISCUSSION

Significant effects of NAC treatment were found for all the three types of hearing measurements. However, the picture is complicated and using the conventional hearing thresholds there is no certain proof that the effects of NAC are for the better. One example is that the introduction of NAC seems to work differently at different frequencies. Another complication might be that the hearing of the two groups is not perfectly matched. – We obtain a bounce for the right, and only the right, ear when not using NAC. One question is if fluctuations towards better and/or worse thresholds are good or not - or if very stable thresholds are the best. We can see examples of both. The hearing thresholds in wNAC have all returned to “before-values” at the latest the day after. In noNAC we just measured thresholds on a couple of subjects the day after.

That the PMTF-maxima might decrease when TEOAEs increase astonished us after the noNAC experiment. That possibility is confirmed by wNAC although we have no explanation as yet. (And the question about learning effects working towards lower thresholds in the second session can be abandoned.) And a new question that we have not been able to explain surfaced: Why do the TEOAEs for the group that were going to get NAC decrease overnight? Since TEOAEs is a commonly and also clinically used method we need to include it in further tests, although it is not clarifying at the moment.

The PMTF group results changed in the direction of a sensorineural hearing loss caused by continuous noise exposure both with and without NAC. Without NAC treatment the results continued to grow worse at least until the measurement the day after exposure. (Swollen haircells?) If the hearing thresholds grew worse until the day after exposure we don´t know. Like for the hearing thresholds the start values of the PMTF (the day before exposure) differed. That underlines the importance of more balanced groups regarding hearing and possibly age. For further planning it may be kept in mind that for those in noNAC that had an extra PMTF-measurement 20 to 30 min after exposure, at m2, there was no difference from the results before exposure. The effects came later.

CONCLUSIONS

The experiments have shown that there are some small temporary effects on hearing from shooting 2 times 20 shots in a bare bunker-like room. The results of the experiment with NAC are promising considering the very limited NAC treatment, the small effects on hearing from the noise exposure and the small and unbalanced test groups. Administration of N-acetylcysteine gave several significant changes in the behaviour of hearing after exposure, with the most logical and clear-cut results for the PMTF-method.
Valuable experience has been achieved for planning new experiments for more reliable proof.

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APPENDIX

This appendix contains test schedule, comprehensive tables and figures on hearing thresholds, PMTF results, and TEOAE results.

Example of test schedule (noNAC, Thursday, week no. 246)

time	rel. time	name:		name:		name:		name:		name:		name:	
		time	**s21**	time	**s22**	time	**s23**	time	**s24**	time	**s25**	time	**s26**
9^{00}	**0.00**	9^{00}	OAEm0										
	0.15		audm0	9^{15}	OAEm0								
	0.30				audm0	9^{30}	OAEm0						
	0.45						audm0	9^{45}	OAEm0				
	1.00		Prep.		Prep.				audm0	10^{0} 0	OAEm0		
10^{15}	**1.15**		Shooting		Shooting						audm0	10^{15}	OAEm0
	1.30		audm1		audm1		Prep.		Prep.				audm0
10^{45}	**1.45**		audm2		audm2		Shooting		Shooting				
	2.00						audm1		audm1		Prep.		Prep.
11^{15}	**2.15**						audm2		audm2		Shooting		Shooting
	2.30		audm3								audm1		audm1
	2.45				audm3						audm2		audm2
	3.00		?		?		audm3						
	3.15				?		?		audm3				
12^{30}	3.30		audm4						?		audm3		
	3.45				audm4						?		audm3
	4.00						audm4						?
	4.15								audm4				
13^{30}	4.30		audm5								audm4		
	4.45		OAEm5		audm5								audm4
	5.00		PMTFm5		OAEm5		audm5						
	5.15				PMTFm5		OAEm5		audm5				
14^{30}	5.30						PMTm5F		OAEm5		audm5		
	5.45								PMTFm5		OAEm5		audm5
	6.00										PMTFm5		OAEm5
	6.15												PMTFm5
15^{30}	6.30												

Example of test schedule: test subjects in wNAC with shootingThursday v.315

Time	name:		name:		name:		name:		name:		name:	
	tid	**n21**	tid	**n22**	tid	***n13***	tid	***n24***	tid	**n25**	tid	**n26**
We v315	11^{30}	premeas.										
			12^{45}	premeas.								
Th v315					13^{45}	premeas.						
8^{45}	8^{45}	OAEm0					14^{00}	premeas.				
		audm	9^{00}	OAEm0					15^{00}	premeas.		
		audm0		audm	9^{15}	OAEm0					15^{15}	premeas.n
				audm0		audm	9^{30}	OAEm0				
						audm0		audm	9^{30}	OAEm0		
		Prep		Prep				audm0		audm	10^{00}	OAEm0
10^{15}	10^{20}	Shooting	10^{20}	Shooting						audm0		audm
		audm1		audm1		Prep		Prep				audm0
10^{45}		audm2		audm2	10^{50}	Shooting	10^{50}	Shooting				
						audm1		audm1		Prep		Prep
11^{15}						audm2		audm2	11^{20}	Shooting	11^{20}	Shooting
11^{30}		audm3								audm1		audm1
				audm3						audm2		audm2
12^{00}						audm3						
12^{15}								audm3				
12^{30}		audm4								audm3		
12^{45}				audm4								audm3
13^{00}						audm4						
13^{15}								audm4				
13^{30}		audm5								audm4		
13^{45}		OAEm5		audm5								audm4
14^{00}		PMTFm5		OAEm5		audm5						
14^{15}	14^{15}			PMTFm5		OAEm5		audm5				
Postmeas. Fr v315		a.m.	14^{30}			PMTm5F		OAEm5		audm5		
				a.m.	14^{45}			PMTFm5		OAEm5		audm5
postmeas. Th v316		a.m.				a.m.	15^{00}			PMTFm5		OAEm5
				a.m.				a.m.	15^{15}			PMTFm5
						a.m.				a.m.	15^{30}	
								a.m.				a.m.
										a.m.		
												a.m.

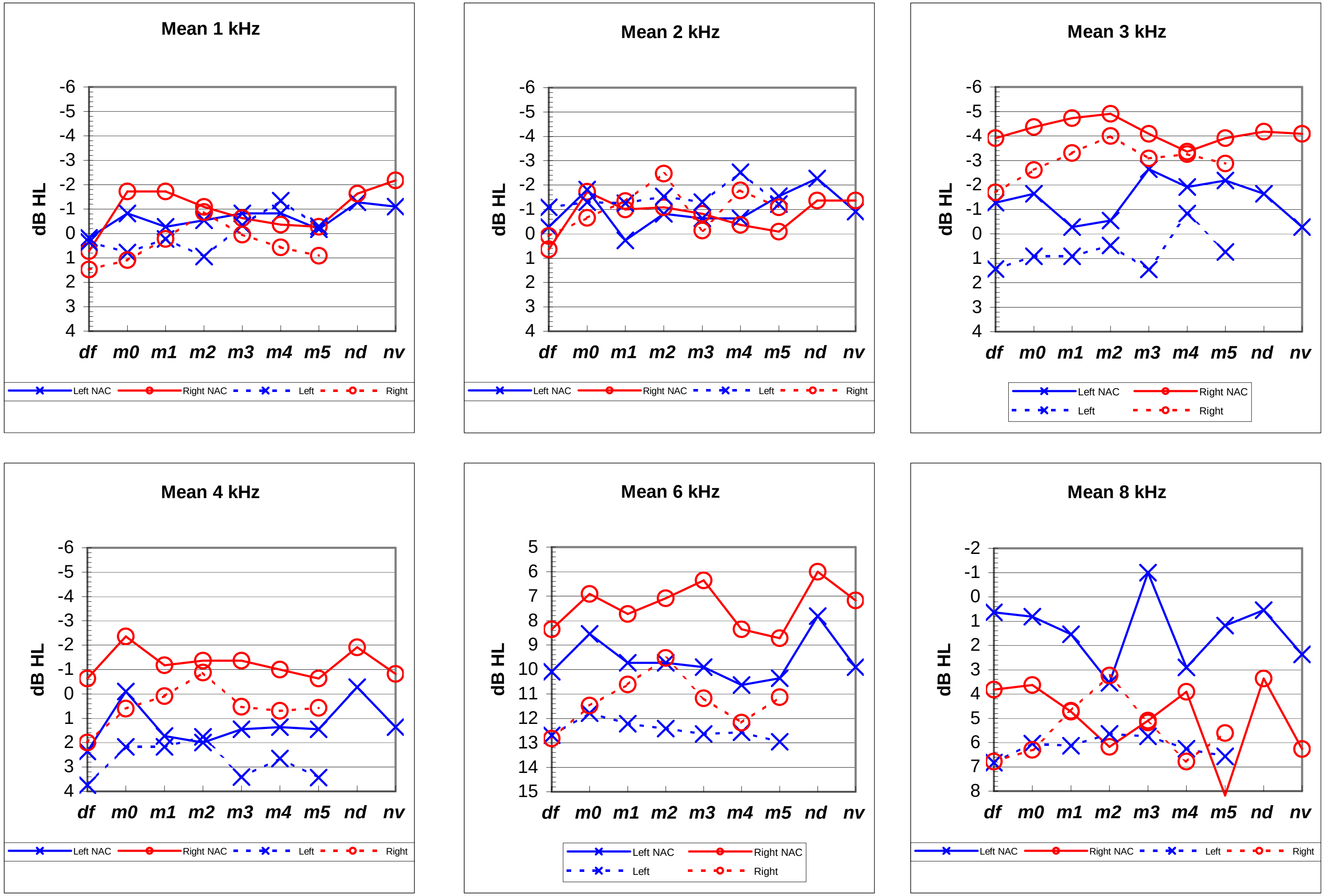

Figure A1. Mean tone thresholds over subjects for the group without NAC (N=23, dashed lines) and the group treated with NAC (N=11, solid lines). Note that the size of 1 dB is the same for all the figures, but the scale has been shifted to facilitate comparison.

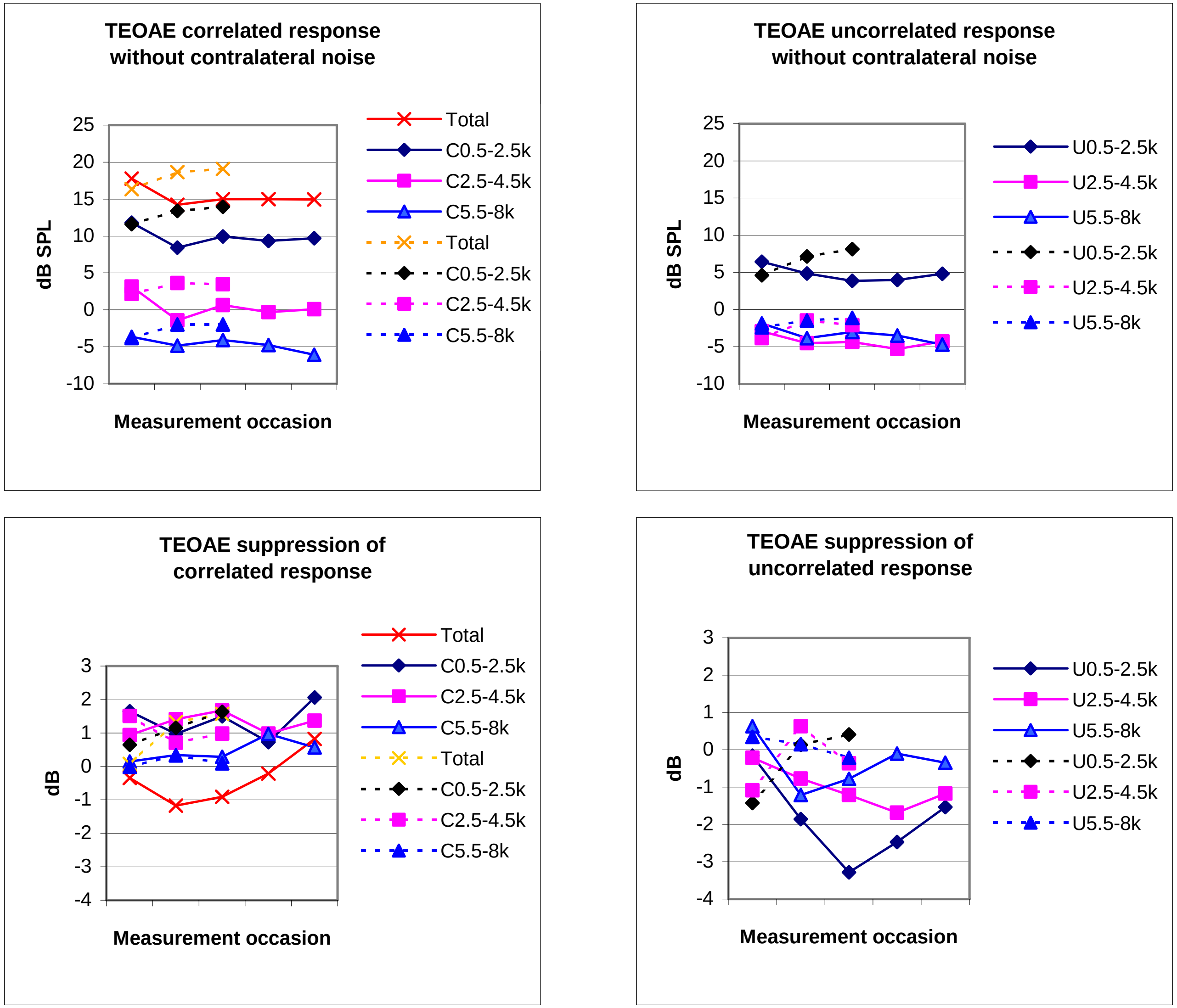

Figure A2. Mean TEOAE results over subjects for the group without NAC (N=23, dashed lines) and the group treated with NAC (N=11, solid lines). Total response over the whole frequency area as well as for the three frequency areas 0.5-2.5 kHz, 2.5-4.5 kHz and 4.5-8 kHz.