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Changes in oto-acoustic emissions after exposure to live music

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Abstract: Distortion Product Otoacoustic Emissions (DPOAE) and Transient Evoked Otoacoustic Emissions (TEOAE) were measured in subjects before and after attendance to live music. The changes measured were compared to the exposure levels measured at the position of the subject. The main objectives of this experiment were two fold: 1) to assess the validity of the proposed measurement protocol to measure changes in DPOAE and TEOAE after a concert; 2) to test the reliability of the oto-acoustic emission measurement system under field conditions; Initial results shows that it is possible to measure changes in hearing after exposures of relative short duration (<1.5 hours). There are large individual differences both in sound exposure levels as well as in the changes on otoacoustic emissions produced by similar exposures. Current results will be presented.

Keywords: Music sound exposure, otoacoustic emissions, hearing

1 Introduction

Adverse effects of excessive sound exposure are normally associated to industrial noise and work related sound exposures [WHO, 1997], yet excessive sound exposure from amplified music has recently been shown to be a potential hearing hazard [Petrescu, 2008, Zhao et al., 2010]. The frequency and temporal characteristics of amplified music are very different than that of industrial noise, which is the basis for the existing damage risk criteria [ISO 1999, 1990, ANSI-S3.44, 1996]. This means that current limits and sound exposure assessment methods may be inadequate when it comes to music sound exposure.

In order to establish safe listening levels for amplified music a dose-response relationship should be derived. A representative sound exposure should obtained (dose), considering the level variations within a music venue and the temporal aspects of the sound exposure. Dosimeters or person mounted microphones should be used by concert attendees. The position of the microphone an its relation with the sound field value used for assessment of risk (i.e. L_{Aeq}) should be well documented.

A measure of the effects on hearing (response) needs to be obtained immediately after the sound exposure. The method chosen must be fast and sensitive to small changes of the auditory function. Traditionally this has been done using absolute hearing thresholds to derive Temporary Threshold Shift (TTS) [Melnick, 1991]. Threshold determinations are subjective estimations of the auditory function, are time consuming and require low levels of background noise. As an alternative, Otoacoustic Emissionss (OAEs) are objective measures of the peripheral auditory system (ear canal, middle ear and inner ear). The existence of OAEs is related to a healthy

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hearing while their absence does not necessarily mean a reduced hearing threshold, indicating that OAEs are more sensitive to changes in hearing than auditory thresholds [Lonsburymartin et al., 1991, Attias et al., 1995, Lucertini et al., 2002].

The aim of the present research is to relate exposure levels measured at live amplified music events to changes of auditory function observed through OAE measurements of human subjects.

This paper presents results from a pilot study done within the *Music as Noise* project, that is running in the framework of the Danish Sound Technology Network[4]. The objectives of this initial experiment were: 1) To test the measurement protocol; 2) To test the reliability of the OAE measurement system under field conditions.

2 Methods

2.1 Subjects

Six volunteer subjects between 23 and 39 years of age (average age of 31,9 years) participated in the experiment. All subjects had hearing thresholds ≤20 dB HL in the frequency range from 0.5 to 8 kHz in $1/2$-octave steps, based on standard pure tone audiometry. None of the subjects reported known hearing disorders and it was possible to measure OAEs in all of them.

2.2 OAE measurements

All OAE measurements were carried out using a custom made MATLAB program, an OAE probe microphone (ER10C, Etymotic Research) and an external USB sound card (Edirol UA-25ex, Roland). For all subjects Transient Evoked Otoacoustic Emissionss (TEOAEs) and Distortion Product Otoacoustic Emissionss (DPOAEs) were measured from both ears.

2.2.1 DPOAE

Sixteen linearly spaced DPOAEs ($f_{dp} = 2f_1 - f_2$) were measured using f_1 in the frequency range of $1160 \geq f_1 \leq 4250$ Hz with $f_2/f_1 = 1,22$ and a fix primary levels of $L_1/L_2 = 65/45$ dB. Each pair of primary tones was averaged in time for 1.3 s, and the sixteen primaries were presented five times in ascending order without refitting the probe. For each measured DPOAE a noise estimate was obtained by averaging the amplitude of all frequency components within an Equivalent Rectangular Band-width (ERB) centered at the distortion product frequency (f_{dp}), but not including it.

2.2.2 TEOAE

TEOAEs were measured using a 80 ms non-linear differential stimulus block consisting of four equally spaced 80 μs pulses (three of equal amplitude and phase, and one with three times the amplitude and opposite phase) presented at an average peak level of 80 dBpeak [Kemp et al., 1990]. From each stimulus block a 20 ms TEOAE estimate was obtained by averaging the signals measured after each pulse. Each TEOAE measurement and the corresponding noise estimate was obtained from 500 repetitions of the stimulus block. A cross correlation between the 250 even and the 250 odd TEOAE estimates were used as an estimate of repeatability of the measured TEOAE (denoted “Wave Repro”), a high Wave Repro implies a strong emission.

2.3 Sound Exposure Measurements

Sound exposure measurements were carried out using behind-the-ear hearing-aids (Oticon Vigo BTE 312, here designated as BTE) reconfigured to work as a dosimeter, with a dynamic range from 40 to 115 dB SPL and a flat frequency response between 80 and 8000 Hz. The sound exposures obtain in this manner do not conform

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with the current standards for sound exposure assessment. Therefore they are only be used as an estimate of the exposure level for comparison between sound exposures measured using the same method. Here the results form these measurements will be reffered to as Ear Exposure Level (EEL)

Three subjects were exposed to a single 90 min concert and were placed at a designated measurement positions in the audience next to a person wearing the BTE. The other three subjects were fitted with a BTE upon arrival to the music venue and instructed to use the device throughout their entire stay. These subjects were free to move around the music venue and participate in different concerts and activities. A summary of the measured EELs is presented in Table 1.

Table 1: EEL for each subject. The first column shows the A-weighted ear exposure level (EEL_{Aeq}), the second column shown the exposure duration and the third column is the EEL_{Aeq} normalized to an 8 hours time period (EEL_{EX}).

Subject	EEL_{Aeq} [dB]	Exp. Time [h]	EEL_{EX} [dB]
M01	112.7	1.50	105.5
M03	111.3	1.50	104.0
F04	106.2	1.50	99.0
M05	94.2	6.28	93.1
M07	96.1	4.68	93.8
F08	83.3	4.13	80.4

2.4 Experimental Procedure

A base line DPOAEs and TEOAEs was measured for each subject, either some days prior to attending the concerts or during the same day, before any sound exposure. After the sound exposure, DPOAEs and TEOAEs were measured in the same manner as for the base line. The post-exposure measurements were carried out in the vicinity of the music venue, in a nearby school for subjects M01, M03 and F04, that participated in the same concert; and in a closed area of the music venue for subjects M05, M07 and F08, that had longer exposures.

3 RESULTS

3.1 DPOAE

Figure 1 shows the average pre-exposure DPOAE (blue) and the average post-exposure DPOAE (red) levels for both ears of all subjects. In all plots the lines with symbols and error bars denote the DPOAE levels and the grey lines without symbols denote the noise floor of the measurement. Each point in the plots is the average of 5 measurements at each pair of primaries. The error bars in the DPOAE level denote the standard deviation over the five repetitions, for the symbols without error bars the standard deviation is smaller that the size of the symbol.

Subjects that participated in the same concert (M01, M03 and F04, right two columns of Figure 1) showed a mild reduction of the DPOAE levels between 3 and 9 dB. Subject M01 that had the highest EEL showed the greatest effects (panel M01-L), while subject F04 that had the lowest EEL showed almost no effect (panels F04-L and F04-R).

Subjects that had longer exposures (M05, M07 and F08 left two columns of Figure 1) showed a large reduction of DPOAE levels reaching a maximum reduction of about 28 dB. For these subjects almost all the post-exposure DPOAE levels were found within the background noise. Nevertheless, the figure shows that with the exception of the right ear of subject M07 (panel M07-R of Figure 1) all of the post-exposure background noise estimates are below the pre-exposure DPOAE levels. If the subjects had not been affected by the sound exposure,

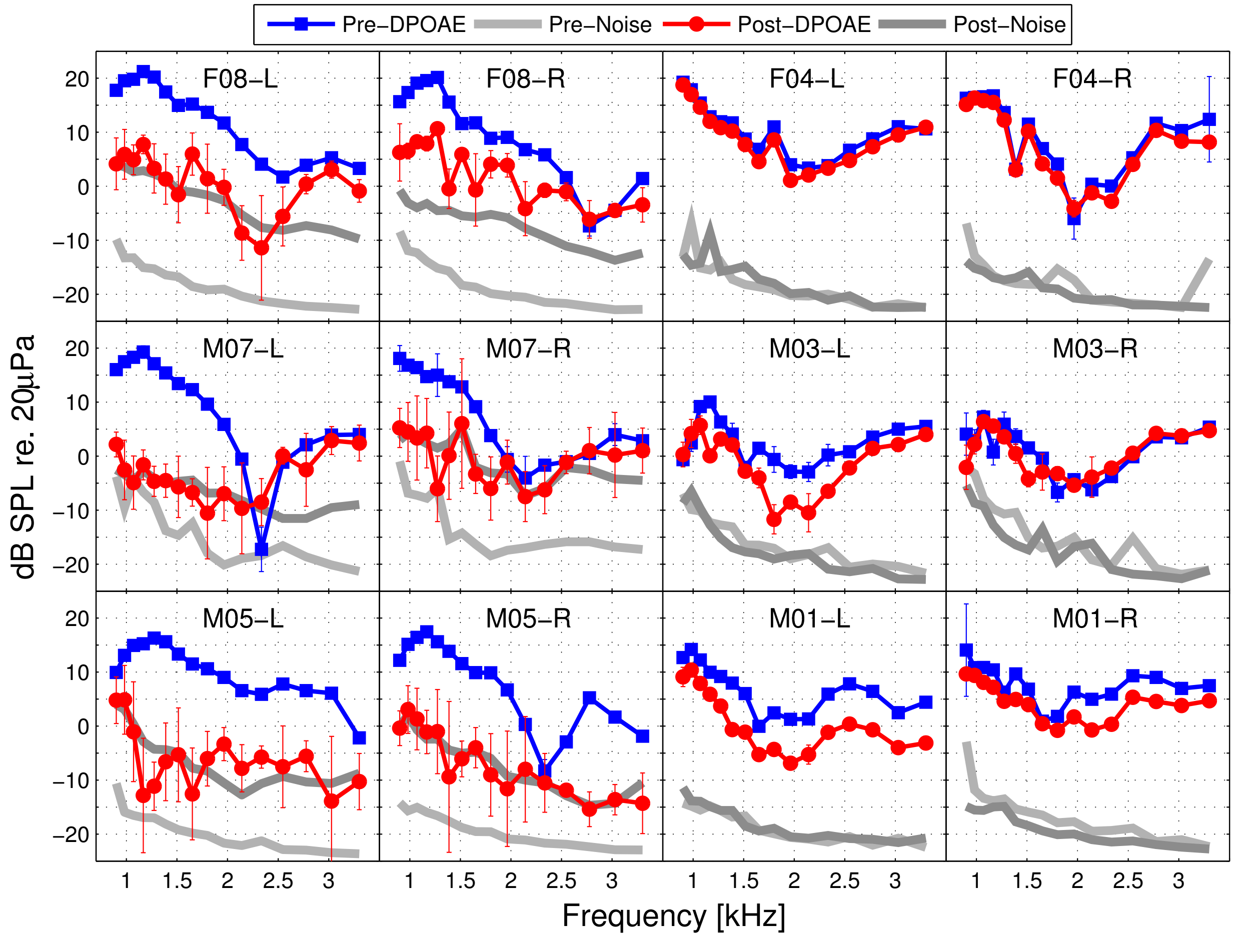


Figure 1: Average pre- (blue) and post-exposure (red) DPOAE levels with the corresponding noise estimate (grey lines) for all ears of the experiment. The text in each panel indicates the subject and ear, i.e. "M01-L" stands for subject M01 left ear.

the DPOAE levels measured after the exposure should still be above the background noise and comparable to the pre-exposure levels. They are clearly not.

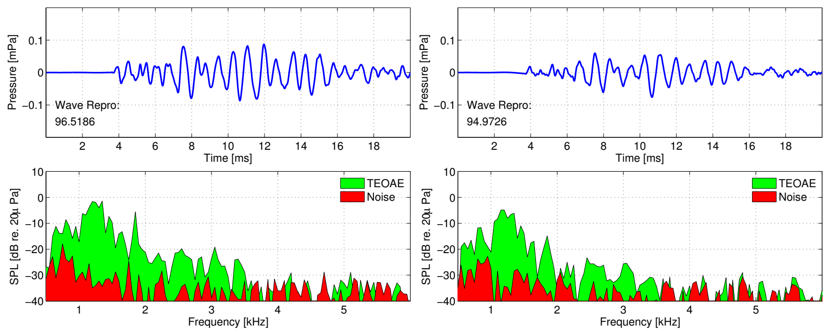
3.2 TEOAE

The results of the TEOAE measurements are presented in Table 2 in terms of the pre- (PR) and post-exposure (PO) TEOAE *Wave repro* values and the correlation between pre- and post-exposure TEOAE (PR-PO). Two examples of TEOAE results can be seen in Figure 2.

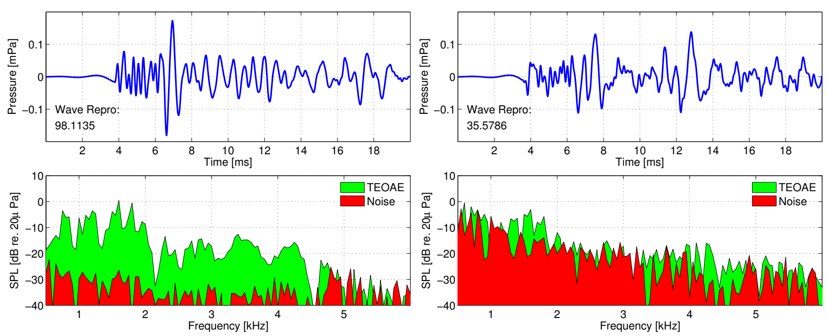
When the hearing is affected by a sound exposure, there is a decrease in TEOAE strength and reproducibility, and therefore there will be more influence of the background noise. This will result in a lower PR value. If the changes in the TEOAE signal involve changes in its frequency or temporal characteristics, pre- and post-exposure TEOAE will not be correlated giving a low PR-PO value. Table 2 shows that post-exposure correlation values for subjects M05, M07 and F08 were considerably lower compared to subjects M01, M03 and F04. This is due to the higher background noise present at the measurement site for these subjects as seen in the lower right panel of Figure 2(b) and on the left two columns of Figure 1.

Table 2: Wave Repro of pre- (PR) and post-exposure (PO) TEOAE measurements and correlation between pre- and post-exposure (PR-PO) TEOAE measurements for both ears of each subject.

	Left ear			Right Ear		
Subj.	PR	PO	PR-PO	PR	PO	PR-PO
M01	93.45	89.22	87.93	96.52	94.97	90.71
M03	34.41	41.77	45.89	84.60	87.83	90.06
F04	99.26	99.20	97.68	97.96	98.92	97.93
M05	91.26	-17.51	3.89	91.60	-4.13	39.02
M07	58.20	16.42	22.96	67.61	23.97	35.44
F08	98.11	35.58	44.67	92.24	57.38	66.13



(a) Subject M01 – right ear



(b) Subject F08 – left ear

Figure 2: TEOAE as a function of time (blue), TEOAE amplitude (green) and noise estimate (red) as a function of frequency. Pre-exposure TEOAEs (left panels) and post-exposure TEOAEs (right panels) for the right ear of subject M01 (a) and for the left ear of subject F08 (b).

4 Discussion

It is clear from the present results that hearing is affected by exposure to amplified live music. The conditions for OAE measurements at the musical venue were not optimal and in the worst cases background noise invalidated the measurements. TEOAE measurements are more susceptible to background noise than DPOAE measurements. This is probably due to the stimuli used in the measurements, for DPOAEs tonal stimuli deliver high amounts of energy concentrated in narrow frequency ranges, while for TEOAEs measurements 80μs pulses excite the entire measured frequency range.

The EELs obtained for each subject cannot predict the changes observed in OAEs. Subjects M01, M03 and F04 that participated in a single concert had higher EELs than subjects M05, M07 and F08, that received longer exposures with different characteristics. Yet the later group of subjects showed greater changes in DPOAE levels after their respective exposures. The main differences in EELs were due to the exposure duration and to fluctuations in level. The sound exposure measurements presented here should only be considered as indicative of typical live music sound exposures. More detailled time and frequency characteristics of the exposures are needed in order to be able to characterize the exposures and relate them to effects observed on hearing.

The present pilot study shows that it is possible to assess the effects on hearing from exposure to amplified live music using the proposed OAE measurement protocol. Better field conditions are needed to insure acceptable levels of background noise during post-exposure measurements. The effects of both long term ($>$ 2 hours) and short term exposures needs to be taken into account.

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