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Distortion Product Otoacoustic Emissions (DPOAE) after exposure to noise and music of equal energy

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Exposure to intense noise and music can result in Temporary Threshold Shifts (TTS). Previous investigations suggest that music and noise may induce TTS differently and that the magnitude of TTS after noise exposure is larger compared to music exposure. Listening to music may induce unknown effects in the medial olivocochlear bundle which may suppress the size of the TTS. Ten normal hearing listeners were exposed for 10 minutes to 100 dB SPL familiar and unfamiliar music or noise on separate days. During the exposure of music or noise the test subjects focused entirely on the auditory stimulus. In a parallel experiment, the subjects had non-auditory attention on a puzzle task (the Tower of Hanoi). The order of the experiments was randomized. Pre- and post-exposure Distortion Product Otoacoustic Emissions (DPOAE) were measured at 2, 3 and 4 kHz. DPOAE response was suppressed on both ears immediately after noise exposure and on the left or the right ear after familiar and unfamiliar music exposure, respectively. Auditory attention compared to non-auditory attention resulted in higher DPOAE suppression on the left ear. In conclusion, music and noise with equal energy suppressed DPOAE responses on both ears but with noticeable differences between ears.

INTRODUCTION

Temporary hearing loss in conjunction with excessive exposure to sound is described as Temporary Threshold Shift (TTS). Musicians would be expected to experience incidences of TTS quite often since they are exposed to loud sound (Schmidt *et al.* 2011). The duration of the TTS is correlated to the magnitude and the length of the sound exposure (Clark 1991).

TTS can occur after exposure to music and industrial noise, but the magnitude of TTS have been reported to be much smaller and TTS duration shorter after exposure

to music sound compared to industrial noise of equal energy. The frequency content of the noise and the music was identical so this difference cannot be explained by the physical properties of the sound (Lindgren and Axelsson 1983; Strasser *et al.* 2003). Furthermore, musical preference seems to have an effect on the magnitude of the TTS. TTS is more profound in subjects disliking the music compared to subjects who like the music (Swanson *et al.* 1987). Furthermore, Axelson and Lingreen (1978, 1981) showed that musicians at a rock concert had less TTS than the audience. The sound exposure of the musicians and the audience was identical.

TTS has been suggested to be a physiological phenomenon involving regulation of outer hair cells through the medial olivo-cochlear (MOC) efferent nerve bundle (Darrow *et al.* 2006). The efferent MOC system is mediated by myelinated cholinergic nerves, which end at the outer hair cells. These nerves exert a sound induced feedback to the outer hair cells, which can increase the threshold of the outer hair cells making them less sensitive to stimulation (Darrow *et al.* 2006). It is speculated that musicians can be protected from TTS induced by music because of increased function of the MOC bundle (Brashears *et al.* 2003). Experiments with musicians have shown evidence for a reduction of otoacoustic emissions after contralateral stimulation explained by an increased function of the MOC bundle in musicians. If contralateral stimulation can lead to a suppression of otoacoustic emissions in the other ear, it must use efferent nerves to exert this effect (Brashears *et al.* 2003).

Experiments have also shown that musicians are more sensitive to constant pure tones than non-musicians. The musicians hear the tones as constant for a longer time compared to non-musicians. Both findings can be an effect of musical training, that may sharpen audition and to lead to an increased function of the MOC bundle (Micheyl *et al.* 1995; Brashears *et al.* 2003). Furthermore, auditory attention in musicians and non-musicians may lead to suppression of the outer hair cells in cochlea through the MOC bundle (Maison *et al.* 2001). Experiments with non-musicians have shown that attention directed towards a simple sound source can reduce the amplitude of otoacoustic emissions (Maison *et al.* 2001). It is not known if music or noise activates the MOC system differently, which may lead to different suppression of otoacoustic emissions, similar to the differences seen after a TTS from either music or industrial noise. It is also not known how auditory attention towards complex music or noise stimuli will influence otoacoustic emissions. Maybe the character of the sound is important for MOC activation. For example, activation of the MOC system has not been observed after stimulation by impulse sound (rifle shot, Wagner *et al.* 2005).

In the present study we have investigated the influence of three different stimuli (noise, familiar and unfamiliar music) with equal energy on the amplitude of the DPOAE to test if the character of the sound influences the DPOAEs differently. Furthermore, we studied the influence on the amplitude of the DPOAEs after auditory attention towards noise or music stimuli.

MATERIALS AND METHODS

Subjects

10 normal hearing subjects volunteered to participate in the experiment. Their hearing thresholds and Distortion Product Otoacoustic Emissions (DPOAE) were recorded on a separate day prior to the experiment. The subjects were interviewed about their previous experience with music.

Stimuli

Three different sound stimuli of 10 minutes were created. One stimulus consisted of a mix of 10 different familiar songs taken from the top 100 of the 500 greatest songs ever as published by www.rollingstone.com. A central part of the song was played for approximately one minute and the shifts between the different songs were made with cross fade. 10 similar unfamiliar songs were selected by a musician. The songs were similar in rhythm to the familiar songs. A comparable stimulus of 10 unfamiliar songs was then created. Finally a stimulus of 10 minutes of noise was made. The noise stimulus had a frequency composition which exactly matched the familiar music. The stimuli were all played at 100 dB SPL for 10 minutes.

Material

Computer-controlled Tucker-Davis Technologies RM-2 processors were used for audiometry tests prior to the experiment. The system was calibrated to use Sennheiser HDA-200 headphones. DPOAE was recorded with Eclipse from Interacoustics, using insert headphones ER-3A. The stimuli during the experiments were played through Sennheiser HDA-200 headphones.

Exposure

Each subject was exposed twice to each of the three stimuli at six different experiment days. Prior to the exposure at the different exposure days the subjects were instructed to pay auditory attention to either the sound (noise or music) or to have non-auditory attention directed towards a specific task (The Tower of Hanoi puzzle). During non-auditory attention they were exposed to noise, familiar or unfamiliar music as well. The order of the different experiments (3 stimuli and 2 tasks) was randomised for all subjects in a balanced design.

Measurements

Before each experiment DPOAEs at 2, 3 and 4 kHz were recorded at the left and the right ear. Immediately after the exposure, DPOAEs at 2, 3 and 4 kHz were recorded at the left and the right ear three times. The time between the different DPOAE measurements was approximately seven minutes. DPOAE responses were compared to the pre-exposure DPOAE responses to calculate the size of the DPOAE depression after the exposure.

Statistics

All data were analysed with linear mixed models with subjects as random effects. DPOAE response differences (pre-post exposure) were used as outcome variables where as stimuli and task was used as independent variables.

RESULTS

Music and noise both suppress the DPOAE response. In Figure 1 it is seen that exposure to the noise stimulus significantly suppressed the DPOAE response with approximately 1.2 dB [95% Confidence Interval (95% CI 0.4-2.1 dB)] to 1.9 dB (95% CI 0.9-2.8 dB) on both the left and the right ear.

However, familiar music significantly suppressed the DPOAE response on the left ear only with 1.7 dB (95% CI 0.8- 2.5 dB), whereas exposure to unfamiliar music suppressed the DPOAE response significantly by 2.0 dB (95% CI 1.0-3.0 dB) on the right ear only. The DPOAE response was barely suppressed and it was not significantly different from the pre-exposure state on the contralateral ear for both familiar and unfamiliar music stimulation.

It is also evident from Figure 1 that auditory attention towards the different stimuli on the left ear seemed to suppress the DPOAE response even more compared to the stimuli where the attention was non-auditory and directed towards the task (the Tower of Hanoi puzzle). Auditory attention significantly suppressed the DPOAE response on the left ear and only after noise and familiar music. When the attention was non-auditory and DPOAEs were measured after noise and familiar music exposure, the DPOAE response was not significantly different from the pre-exposure measurements. On the other hand, the DPOAE response was still significantly suppressed on the right ear after non-auditory attention during exposure to noise and unfamiliar music.

To investigate the effects of auditory attention even further, DPOAE responses in experiments with auditory attention were compared to experiments with non-auditory attention. In this statistical analysis the type of stimuli was included as independent variable to account for the effects related to the stimulus. The task was as well included as independent variable. Figure 2 shows that auditory attention leads to a significant suppression of 1.0 dB (95% CI 0.3-1.6 dB) of the DPOAE response of the left ear compared to the pre exposure DPOAE measurement. Non-auditory attention gave a small and non significant suppression of 0.2 dB (95% CI -0.4 -0.9 dB) of the left ear. The difference between auditory and non-auditory attention was significant ($p < 0.03$). The right ear is shown in Figure 3. Auditory and non-auditory attention leads to significant suppression of the DPOAE response of 1.3 dB (95% CI 0.7-2.0) and 1.2 dB (95% CI 0.5-1.9 dB) respectively. However, no significant difference in DPOAE suppression could be observed between auditory and non auditory attention on the right ear.

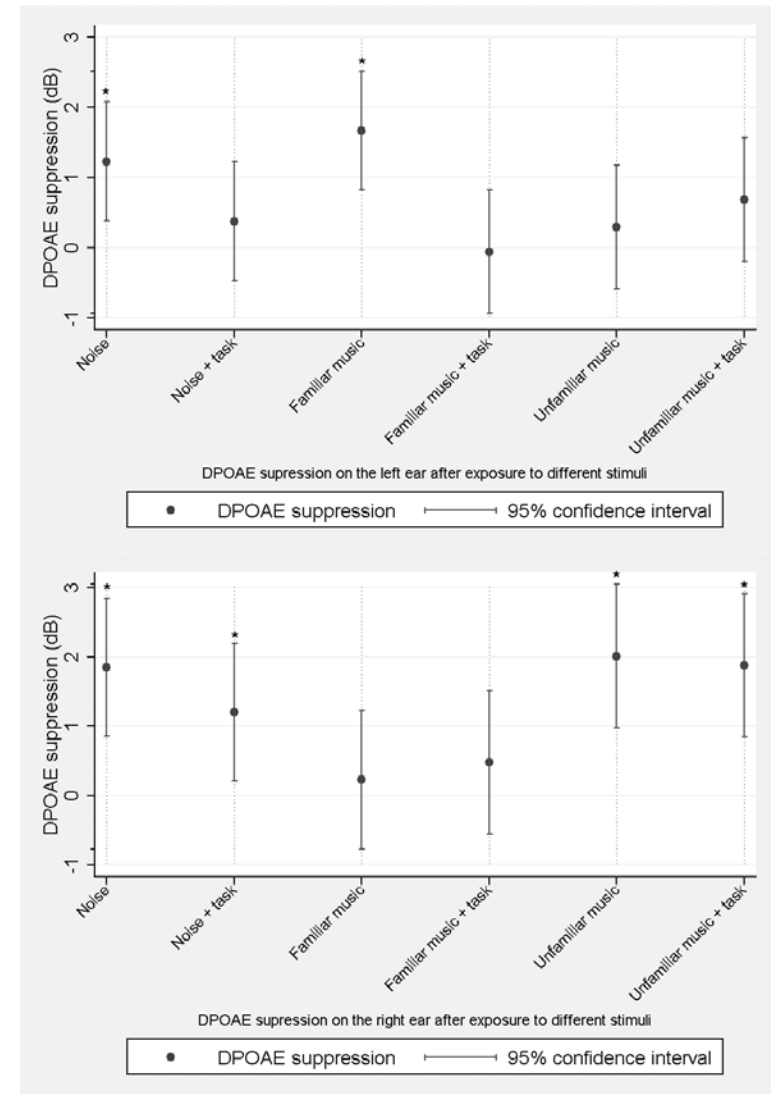


Fig. 1: Mean 2, 3 and 4 kHz DPOAE suppression of the left and the right ear in dB immediately after exposure to noise, familiar music and unfamiliar music. Task indicates if subjects had non auditory attention towards the puzzle Tower of Hanoi during the exposure to the different stimuli. In other situations without task the attention was directed towards the sound stimulus. (*)Indicates if the suppression of DPOAE is statistical different from the DPOAE response prior to exposure.

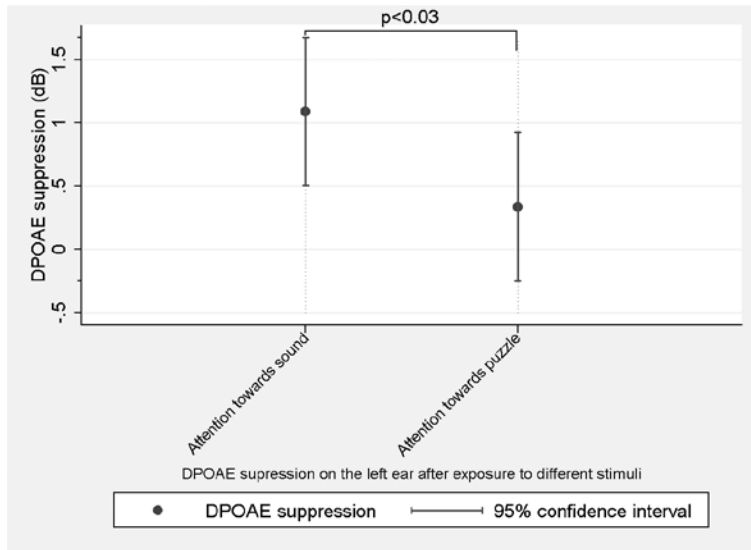


Fig. 2: DPOAE suppression with and without auditory attention of the left ear. During stimulation and non-auditory attention, the attention has been directed towards the puzzle Tower of Hanoi.

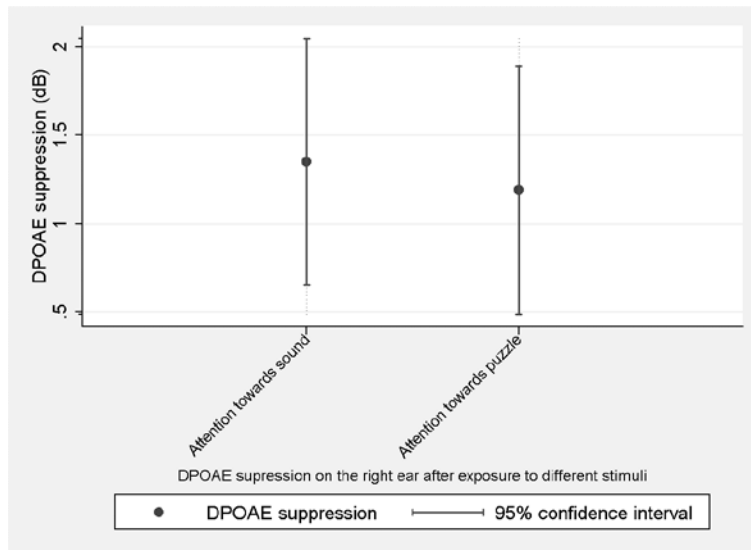


Fig. 3: DPOAE suppression with and without auditory attention of the right ear. During stimulation and non-auditory attention, the attention has been directed towards the puzzle Tower of Hanoi.

DISCUSSION

Both music and noise with equal energy can suppress DPOAEs immediately after exposure to loud intensive sound. However, there seems to be interesting differences that may be dependent of the character of the sound. Noise seems to suppress DPOAEs on both ears with a possibly stronger response on the right ear. This is consistent with previous results which have shown a stronger suppression of the DPOAE response at comparable frequencies on the right ear as well after contralateral suppression (Atcherson *et al.* 2008). On the other hand familiar music suppressed the DPOAE response on the left ear, whereas the DPOAE response was suppressed primarily on the right ear after exposure to unfamiliar music. To our knowledge differences on the DPOAE response after exposure to various stimuli have not been described. However, TTS has been shown to be more profound if subjects disliked the music compared to TTS after exposure to music they liked (Swanson *et al.* 1987).

A possible explanation for these differences can be found in studies with musicians. Musicians are described to have increased function of their MOC-bundle which can suppress the DPOAE response more than in non-musicians (Brashears *et al.* 2003). It is speculated that this effect is a result of musical training. Auditory attention has previously been shown to suppress the amplitude of otoacoustic emissions and it is consistent with the findings in the present study (Maison *et al.* 2001). If auditory attention and different sound stimuli (noise, familiar music and unfamiliar music) can exert different effects on otoacoustic emissions, it may suggest that cortical top-down effects can alter the regulation of the outer hair cells in cochlear through cochlear efferent nerves.

CONCLUSIONS

Noise and music can suppress DPOAEs. However, there are noticeable differences between the left and the right ear and the different stimuli. Noise will suppress the DPOAE on both ears whereas familiar music preferably suppressed the DPOAE response on the left ear and unfamiliar music preferably suppressed the DPOAE response on the right ear.

Auditory attention leads to larger DPOAE suppression at least on the left ear compared to situations without auditory attention.

It may be speculated that the reason for these findings can be related to neural basis of the perception of various sound stimuli. Familiar and unfamiliar music may be processed differently in the brain as the brain will analyze and recognize the familiar music differently compared to the unfamiliar music, and the activity in efferent pathways may reflect the different processing.

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Effects of binaural auralization via headphones on the perception of acoustic scenes

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The auralization of an acoustic scene can be realized with the presentation of binaural signals via headphones. One of the biggest challenges is the individualization of the headphone equalization and the generation of the binaural signals. A promising way is the use of probe microphones for equalization and recording. Very good results in terms of externalization and correct reproduction of the acoustic scene can be reached. However, former investigation indicates consistently that perceived acoustic illusion is much more plausible if the recording and the playback conditions are similar or even the same. Within this contribution we present a fully individualized binaural auralization system via headphones. Binaural recordings of sound sources on different representative positions in two real rooms with distinct different room acoustics are made. These recordings are presented via headphones to test persons. A series of listening tests show the expected influence of an accurate individualization on the correct localization of the synthesized sound source. Furthermore, a strong influence of congruence between the room acoustics of listening and recording room on the perception of the scene was observed. We can show that there is a significant decrease of perceived externalization if the listening rooms and the recording rooms are different.

MOTIVATION

Observations from former investigations (e.g., Møller *et al.* (1999) and Klein and Werner (2011)) consistently show that perceived acoustic illusion is much more plausible if the recording conditions are similar or even the same as the listening conditions. At first, the influence of room acoustics is investigated. Other dependencies like audio-visual effects (Abou-Elleal (2003)) and adaptation effects are investigated consecutively. However, for this contribution we dispose the following hypothesis. H1: Perceived externalization of a single sound event synthesized by a binaural headphone system is less if the room acoustics of the listening room does not match the room acoustic of the recording room. This hypothesis is verified with listening tests. In this study, the term plausibility describes the perceived quality features of localization accuracy and externalization of the sound event regarding to different room conditions, customization methods, and sound source positions.