Are temporary threshold shifts reflected in the auditory brainstem response?

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Background: Temporary hearing loss in connection with excessive exposure to sound is described as temporary threshold shift (TTS). The auditory cortex has neural pathways, which directly affect the medial olivocochlear system (MOCS) via the descending efferent auditory system. One of the functions of MOCS may be to protect the inner ear from noise exposure. *Objective*: To investigate the influence of a TTS measured with auditory brainstem responses (ABRs) using noise, familiar, and unfamiliar music as auditory exposure stimulus, respectively. *Method*: Normal-hearing subjects were exposed to the three different sound stimuli in randomized order on separate days. Each stimulus was 10 minutes long and the average sound pressure level was 100 dB. ABRs (4-kHz tone burst) were measured pre-exposure and also immediately after the sound exposure. *Results*: Preliminary results show a tendency towards an increase in the ABR amplitude for Jewit I and a decrease in the ABR amplitude for Jewit V for the left ear after sound exposure. Jewit I represents action potentials in the spiral ganglion neuron, and Jewit V represents action potentials further up the brainstem.

INTRODUCTION

Exposure to high sound levels may entail a temporary threshold shift (TTS), which is described as a temporary hearing loss in connection with immoderate sound exposure. If the hearing loss persists, the threshold shift is considered to be a permanent threshold shift (Quaranta *et al.*, 1998).

As a part of the auditory efferent neural pathway, the medial olivocochlear system (MOCS) originates from the medial superior olive (MSO) and project mainly onto the contralateral cochlear and forms synapses with outer hair cells (OHC) (Fig. 1). MOCS inhibits OHC motility and one of the MOCS functions may be to protect the inner ear from noise exposure (Perrot and Lionel, 2014).

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The auditory cortex has neural pathways, which directly affect MOCS via the descending efferent auditory system (Fig. 1) (Perrot and Lionel, 2014). Studies investigating auditory selective attention and visual attention have shown contradictive results regarding the influence on MOCS (Perrot and Lionel, 2014). Because of the negative and contradictive results further work is needed to clarify the effects of auditory attention.

It is known that different sound characters (music and noise) induce different levels of TTS when comparing noise with music (Strasser *et al.*, 2003). Maybe the character of the sound is important for MOCS activation too?

A TTS can be measured in several ways including normal audiometry and otoacoustic emissions (Kemp, 2002). The immediate change of the ABR after sound exposure has not been studied in humans. However, ABR is affected in normal hearing subjects with tinnitus (Schaette and McAlpine, 2011) and previous noise exposure within 12 months before ABR measurement (Stamper and Johnson, 2015).

This paper gives an overview over the temporary findings in a one-year research project where the temporary changes of the ABR have been studied.

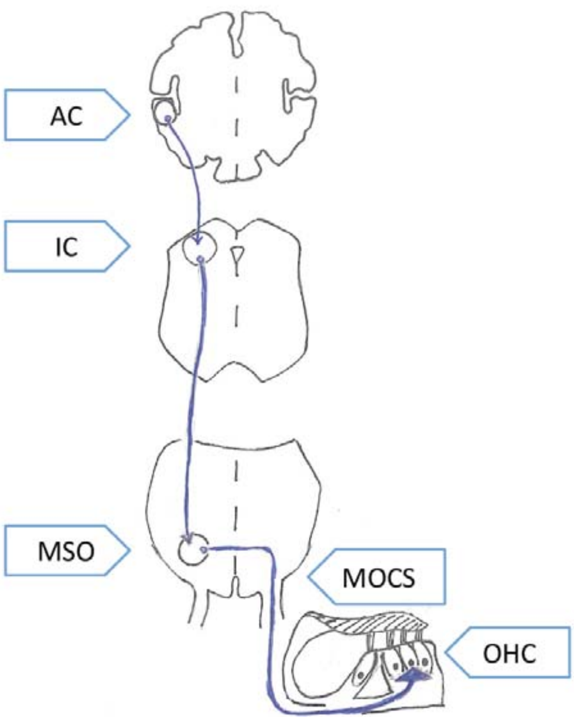

Fig. 1: A simplified representation of the descending efferent auditory system: AC (auditory cortex), IC (inferior colliculus), MSO (medial superior olive), MOCS (medial olivocochlear system), and OHC (outer hair cell).

AIM

To investigate the influence of a TTS measured with auditory brainstem responses (ABRs) using noise, familiar, and unfamiliar music as auditory exposure stimuli.

METHODS

Subjects

Thirteen normal-hearing subjects have participated in the experiment to date. They were recruited using posters at the University of Southern Denmark, at social Internet sites, and similar or related locations. The inclusion criteria were defined as normal ear canals without obstructing cerumen and hearing thresholds better than 20 dB hearing level (HL) at the frequencies 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz evaluated by a two-alternative forced-choice (2AFC) audiometry test (Schmidt *et al.*, 2014). The exclusion criteria were impaired hearing at the first 2AFC audiometry test, smoking (due to a possible influence on the nervous system), and chronic or acute disease in the middle ear.

The test subjects were between 22 and 27 years old (mean of 24 years) consisting of six males (46%) and seven females (54%). One out of the 13 test subjects was left-handed, whereas the remaining 12 were right-handed.

Exposure

The subjects were binaurally exposed to three sound stimuli: music shaped noise, known music, and unknown music. Each stimulus was 10 minutes long and the average unweighted sound pressure level was 100 dB (97 dBA), hereby sufficiently below the Danish noise regulations for work places (L_{eq} of 85 dBA for eight hours). The National Committee on Health Research Ethics have accepted the project. The known music was selected among the top 100 songs of the 500 greatest songs published by www.rollingstones.com and consisted of ten different songs. A central part of each song was played for approximately one minute. The known and unknown music was matched by rhythm. The music shaped noise was made from a white noise signal that was shaped to have same frequency composition as the known music.

While exposed, the test subjects were randomized to the task of auditory attention or non-auditory attention. For each of the two attention tasks the test subjects were exposed to the three sound stimuli in random order, i.e., each subject was exposed to six different test conditions on six different days. The different test conditions are shown in Fig. 2. The non-auditory attention task was the “Tower of Hanoi” – a mathematical, analytical, and motor cortex-demanding puzzle. The subject was presented with the task in order to avoid evoked activity of the hearing sense. The part of the study presented in this article does not investigate the effect of auditory attention and the type of sound stimuli, because a balanced randomization between attention and stimuli was not completed at this time.

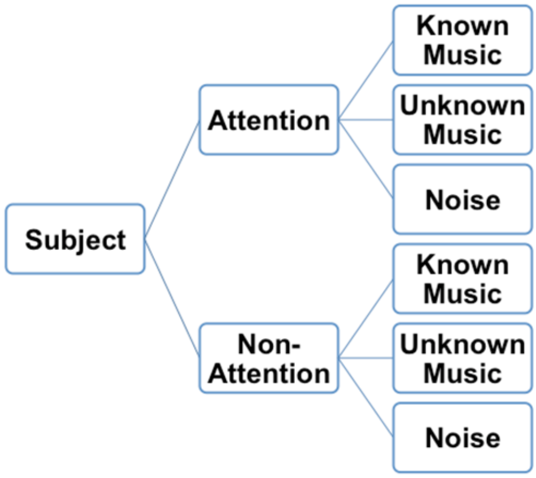

Fig. 2: An overview of the six different test conditions. The subjects were presented with the different conditions on separate days. The order in which each subject was presented with the different conditions was randomized.

Measurements

A small questionnaire and a test of musicality, called the Advanced Measures of Music Audiation (AMMA) test, were obtained before sound exposure. Pre- and post sound exposure ABRs at 4 kHz for 90 dB nHL tone bursts and 2AFC audiometry tests (pre exposure: 1, 2, 3, and 4 kHz and post exposure: 4 kHz) were conducted (Fig. 3). The pre exposure ABR test (pretest) consists of two measurements that are combined in the analysis. The post exposure ABR test consists of three measurements (test 1-3) that are used separately in the comparison to the pre exposure ABR test. After sound exposure, debriefing was used to check if the subject was paying sufficiently attention to the task and his/hers acquaintance with the music. Pre- and post sound exposure measurements of distortion product otoacoustic emissions (DPOAEs) were also a part of the overall study design but are not dealt with in this paper.

Material

A computer-controlled RM-2 processor (Tucker-Davis Technologies) was used for audiometry. ABRs were recorded with Eclipse (Interacoustics), using ER-3A insert headphones. Sennheiser HDA200 headphones were used for sound exposure.

Statistics

All data were analyzed with linear mixed models with subjects as random effects. At the time of data analysis, not all 13 subjects had completed tests for all six conditions. Their randomization in sound stimuli and attention was thus not complete. This was taken into account in the statistics.

Fig. 3: Pre and post exposure measurements in the overall study design by order. Distortion product otoacoustic emissions (DPOAEs) are not dealt with in this paper. The DPOAE, audiometry test, and auditory brainstem response (ABR) were performed before and after sound exposure. The DPOAE and ABR were measured alternately, starting with the DPOAE.

RESULTS

The ABR amplitudes (Jewit I to V) represent the action potentials from the spiral ganglion neuron and throughout the brain stem to the inferior colliculus.

With the difference in amplitude between Jewit I and Jewit V (DiffVI), calculated as V_Amplitude – I_Amplitude, as the response, a linear mixed model was created to describe the difference in DiffVI prior (pretest) and after (test 1-3) sound exposure, with the data not divided into type of sound stimuli or attention task.

Preliminary results showed a significant negative change in DiffVI for the left ear between pretest and test 1 [mean = −0.06, $p = 0.00$], and between pretest and test 2 [mean = −0.06, $p = 0.01$] (Fig. 4). No significant change of DiffVI was observed for the right ear (Fig. 4).

The AMMA score, represented as the combined tone and rhythm score (AMMA_Com), showed a significant increase of DiffVI for the left ear [mean = 0.01, $p = 0.03$] (Table 1) and the right ear [mean = 0.01, $p = 0.00$] (Table 1).

Other significant factors were age for the right ear [mean = 0.02, $p = 0.00$] (Table 1) and FMP, which is a quality number of the ABR response, for the left ear [mean = −0.00, $p = 0.01$] (Table 1).

During backwards-stepwise elimination analysis the type of stimuli variable showed no influence on the results and was thus eliminated from the final model.

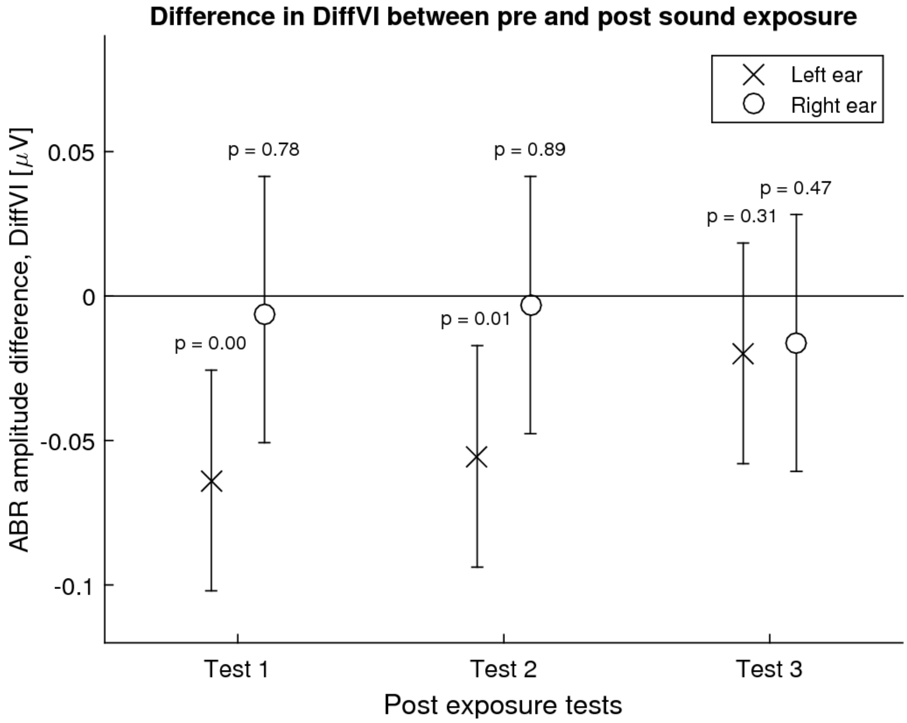

Fig. 4: The mean difference in DiffVI (V_Amplitude – I_Amplitude) with 95% confidence interval between pretest and post exposure tests 1-3, with the data not divided into type of sound stimuli or attention task. The figure shows results for both the left and the right ear.

DISCUSSION

The overall study design includes 20 subjects with complete randomization. This paper only included 13 subjects with incomplete randomization in sound stimuli and attention, therefore the data were not divided into different sound stimuli (music shaped noise, known music, and unknown music) and tasks (attention and non-attention).

Preliminary results showed a significant negative change in DiffVI for the left ear between pretest and test 1 as well as between pretest and test 2 (Fig. 4). This negative change showed a tendency towards a suppression of Jewit V and/or an excitation of Jewit I on the left ear after sound exposure.

The difference in the findings between the right and the left ear may be due to some kind of lateralization of the auditory system, which may be related to the handedness lateralization. Only one out of the 13 test subjects in this sample was left-handed. Maybe right-handed listeners have better protection of their right ear due to a more dominant descending auditory system of MOCS that mainly innervates the contralateral outer hair cells (Fig. 1). Further work is needed to investigate this consideration.

		Coef.	p	95% conf. interval
Left: DiffVI	AMMA_Com	0.01 *	0.03	0.00 ; 0.02
	Female	0.00	1.00	−0.10 ; 0.10
	Age	0.02	0.12	−0.01 ; 0.05
	Right hand	−0.06	0.38	−0.20 ; 0.08
	FMP	−0.00 *	0.01	−0.00 ; −0.00
	Constant	−0.84	0.04	−1.65 ; −0.03
Right: DiffVI	AMMA_Com	0.01 *	0.00	0.01 ; 0.01
	Female	0.02	0.41	−0.03 ; 0.06
	Age	0.02 *	0.00	0.01 ; 0.03
	Right hand	−0.05	0.14	−0.13 ; 0.02
	FMP	0.00	0.80	−0.00 ; 0.00
	Constant	−0.79	0.00	−1.12 ; −0.46

Table 1: The other covariates in the model, for the left and the right ear. AMMA_Com (tone and rhythm scores), Right hand (dominant hand), FMP (quality number of ABR response), constant (the regression constant for the linear mixed model). * Statistically significant difference at a 5% significance level.

The AMMA score had a significant positive change in DiffVI for both ears (Table 1). This shows a tendency towards the ABR can be affected by a person's level of musicality after sound exposure, which is comparable to other investigation of auditory training effects seen in musicians (Micheyl *et al*., 1995).

The lateral asymmetry in human auditory processing is described as domain-specific lateralization (speech/music) or parameter-specific lateralization where the left and right hemispheres are specialized to process respectively rapid temporal changes and tiny changes in pitch (Tervaniemi and Hugdahl, 2003). The sound stimuli in our study contained both temporal and spectral aspects but the quantity of the two in each type of stimulus had not been matched and all sound stimuli data were unified. Maybe this influenced the results for the left and the right ear. The subjects' familiarity with the sound stimuli and their musical abilities were taken into account in the statistics, but not their training in language—all variables that may influence the pattern of lateralization (Tervaniemi and Hugdahl, 2003). The types of stimuli and number of experimental days were also considered in the study along with the variables in Table 1.

The non-attention task was chosen to avoid evoked activity of the hearing sense, by being a mathematical, analytical, and motor cortex-demanding puzzle.

CONCLUSION

A significant negative change in DiffVI (the difference in ABR amplitude between Jewit I and Jewit V) was shown between pretest and test 1 after sound exposure as well as between pretest and test 2 after sound exposure for only the left ear. This may be caused by an excitation of Jewit I and/or a suppression of Jewit V after sound exposure.

The AMMA score had a significant positive change in DiffVI for both ears. This may point at a trend towards the auditory brainstem response after sound exposure being affected by how musically trained a person is, regarding tone and rhythm.

The presented data are preliminary results from an ongoing one-year research project. Results from more test subjects will be presented at a later stage.

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