Exploring MEMR and natural sound with a connection with hyperacusis

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Introduction

The Middle Ear Muscle Reflex (MEMR) is an involuntary response of the stapedius muscle to loud sounds. Activation of the muscle stiffens the tympanic membrane and thereby reduces the amount of energy transmitted into the ear protecting the auditory pathway from potential damage. MEMR is usually assessed in laboratory environments and clinics using artificial sounds like tones (500 Hz, 1 kHz or 2 kHz) or noise (wide band, WB or narrow band, NB) from 70 to 100 dB SPL as stimuli. These sounds have only very low ecological validity and can be perceived as uncomfortable. As a hearing screening tool, the MEMR provides an indication about the health status of the auditory system using a simple presence/absence criterion. The MEMR characteristics can, however, vary substantially from subject to subject, even in case of similar hearing profiles.

Hyperacusis is defined as an increased sensitivity to everyday sounds, and often intended as an umbrella term that also includes noise sensitivity and misophonia. But hyperacusis is specifically related to the level of the sound, that can cause perception of discomfort and sometimes pain at levels that are generally not characterized as uncomfortable by the average listener.

Saxena et al. (2020) explored the relationship between MEMR and hyperacusis. The results showed that MEMR thresholds were higher in the group of participants with hyperacusis with respect to the controls. Hence, the activity of the middle ear muscle and the perception of sound intensity in terms of loudness and pleasantness could be interconnected.

In a preliminary experiment done on two participants with 16 sounds, 5 of which artificial (4 tones: 0.5, 1, 4, 8 kHz and WB noise) and 11 natural ('fork scratch on a plate', 'fingernails on chalkboard', 'female scream', 'cymbal crash', 'breaking glass', 'car horn', 'clapping', 'distorted guitar', 'bell', 'guitar chord', 'harp'), it was found that the MEMR strength differed for the different sounds, despite being presented at the same intensity.

In this study, we explore the characteristics of the MEMR with natural sounds and compare them with the results obtained with artificial sounds. In addition to the MEMR, we collected a subjective evaluation of the sound perceived in loudness and unpleasantness and the answers to the Hyperacusis Questionnaire (HQ; Khalfa English, 2002). We also performed the Core Discriminant Sounds (CDS) test (Enzler et al. 2021) to determine the level of hyperacusis. With these measures we wanted to get information about the personal predisposition towards the sounds, since the presence or not of hyperacusis and noise sensitivity could play a role in the reflex response (Saxena, 2020).

We hypothesize that the MEMR growth function will be shallower for participants showing trends towards increased hearing sensitivity and hyperacusis in the questionnaires and/or the CDS score. Moreover, we hypothesize that, at the same physical intensity, natural sounds are able to elicit a stronger or comparable MEMR response compared to artificial sounds, potentially with lower annoyance and lower perceived loudness.

Methods

Measurement of the MEMR

The MEMR was collected ipsilaterally with the Titan system (Interacoustics) and a custom software implemented in MATLAB. The levels of the stimulation ranged from 60 to 100 dB SPL with 5 dB step and used a procedure adopted from KEEFE ET AL 2010. The MEMR strength was quantified as energy difference in third octave bands between the intervals without the presence of an elicitor (baseline) and the averaged following 4 intervals with the elicitor. The third octave bands had center frequencies logarithmic spaced between 250 Hz and 8000 Hz. The resulting difference was then referred to as "delta absorbance" and used as a frequency-dependent measure of the MEMR. To reduce the delta absorbance to a single number, the mean of the absolute value of the delta absorbance was used to quantify the MEMR strength. The pressurisation done before starting the procedure was done considering the tympanometric peak pressure (TPP), that is the maximum in the measured wide band tympanometry (WBT). The WBT consisted of a 100 dB SPL sweep (250-8000 Hz) which altered the pressure in the ear canal in the range -300 to 200 daPa.

Experiment 1

In the first experiment, 14 young (mean age 23,5; range 21-26) normal hearing (threshold $<$ 20 dB HL for octave frequencies between 125-8000 Hz) subjects were recruited. They were asked to fill the HQ and to answer some questions about their hearing, such as, if they had tinnitus and if they could perceive having problems with loud sounds. In total five sounds were selected: 2 artificial ("Pure Tone 500Hz", "Wide Band Noise"), and 3 natural ("Clapping", "Fingernails on Chalkboard", "Cymbal Crash"). Together with the MEMR, the loudness and the pleasantness of each sound for each level was

measured with a Visual Analogue Scale (VAS) through a Matlab GUI which translated the visual results in values from 1 to 100 as output. All sounds were shortened to a duration of around 100 ms and scaled using the Root Mean Squared (RMS) of a 1 kHz Pure Tone as reference. Only the "Cymbal Crash", due to its transient characteristics, was calibrated such that the peak intensity in dB SPL matched the RMS of the pure tone.

Experiment 2

In the second experiment, 6 normal hearing listeners participated. Two belonged to the old group and 4 belonged to the young group. Hyperacusis was assessed for all listeners with HQ and the same VAS as experiment 1. Eleven sounds were chosen for this experiment: 3 artificial sounds ("Pure Tone 500 Hz", "Pure Tone 1000 Hz", and "White Noise") and 8 natural ("Breaking Glass", "Car Horn", "Clapping", "Distorted Guitar Neck Dissonance", "Female Scream", "Fingernails On Chalkboard", "Fork Scratch Plate", "Guitar Chord", "Harp", "Bell", "Cymbal Crash"). The sounds were chosen to elicit different psychological reactions, either positive, negative or generating annoyance. The procedure was very similar to the first experiment: first assessment, MEMR measurement with the Titan, at the same time with the loudness and unpleasantness assessment through the VAS implemented in a MATLAB Gui. In contrast to experiment 1, the duration of the stimulation was extended to 500 ms to increase the ability of the listener to recognize the sounds.

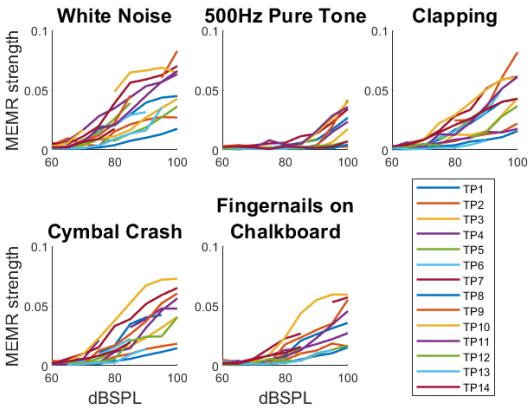

Figure 1: MEMR strength for each sound across the different participants, each represented in a different color.

Results

Experiment 1

The HQ scores were variable across participants and mainly didn't exceed the threshold usually defining hyperacusis, that is 22 (except for participants 3 and 14; for the whole group: range: 2-31, mean: 15.07), four participants (1, 3, 5, 14) said to have tinnitus. The CDS scores also showed a high variability (range: 0.84-64; mean: 24,67) and exceeded 19, the threshold calculated in Enzler et al., for participants 3, 4, 5, 6, 7, 11, 13, 14. With some participants having very discordant results between the two hyperacusis measurements (for example: participant 7: HQ = 15, CDS = 64; participant 4: HQ = 2, CDS = 37.4). More specific details of the assessment are shown in the Table 1. Figure 1 shows an expected monotonic behaviour of the MEMR strength with level of stimulation, however, not every sound presented seems to be equally effective in stimulating the reflex. The wide band noise elicits the stronger responses on average while the pure tone at 500 Hz the weakest. As anticipated, for some participants exist some sounds that have a similar response but different degrees of annoyance and perceived loudness; this is shown in Figure 2. In the figure, each panel represents one sound, and the blue and red lines represent the subjective rating (measured with the VAS scale for each level) of unpleasantness and loudness, respectively. The dotted vertical lines represent, instead, the level for which the MEMR response reached at least the threshold of 0.03 (so there was an activation). If we compare the "White Noise" and the "Cymbal Crash" panels we can see that the dotted lines are present from level 75 dB, that represent the threshold level, but for "Cymbal Crash" the subjective rating is way more steady than for "White Noise", so perceived as less loud and unpleasant for higher levels. This result might be useful for future applications, choosing a customised sound for particularly sensitive listeners. In figure 3, an example shows that there is no direct relation between unpleasantness and MEMR response, differently from what was hypothesized (Panel: "Fingernails on Chalkboard"). Finally, there is no correlation between the MEMR strength and the HQ or the CDS score. In addition to this, there is no correlation between the two measures used to characterize hyperacusis.

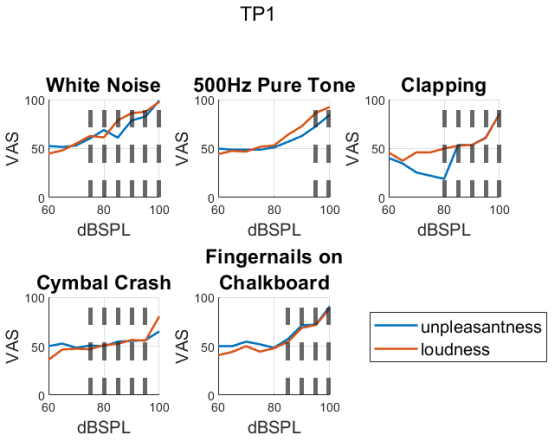

Figure 2: Experiment 1: VAS of unpleasantness and loudness for participant 1, for each sound. The vertical dotted lines are in correspondence to levels where the MEMR was over the threshold.

Experiment 2

Exemplary results from experiment 2 are shown in Figure 4. The data show a different behaviour than the data in Figure 1. The monotonicity is only present for a subset of the participants and the MEMR strength values are around 20 times higher without considering the participant represented by the orange bold line. The sounds, however, were clearly distinguishable from the partici-

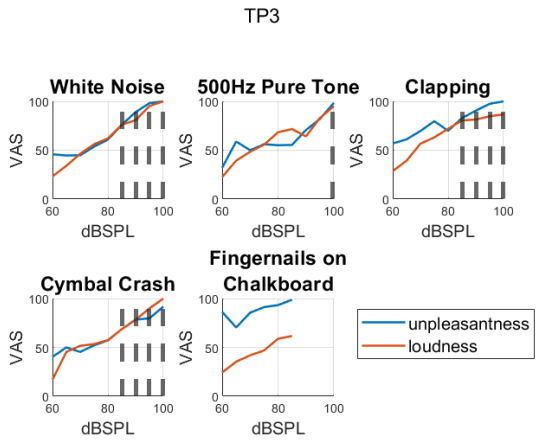

Figure 3: Experiment 1: VAS of unpleasantness and loudness for participant 3, for each sound. The vertical dotted lines are in correspondence to levels where the MEMR was over the threshold.

pant, as intended in the setup of the experiment. From a clinical perspective, it was expected that the elongation of the stimulation could change the outcome of the MEMR, especially since we are using more complex activator signals. In fact, the fact that the MEMR response is usually measured with transient sounds doesn't give information about the nature of the reflex, that could be transient itself or reach a sort of steady state, or even be variable depending on the subject. This consideration gives some uncertainty on the output when the stimulation is not transient anymore.

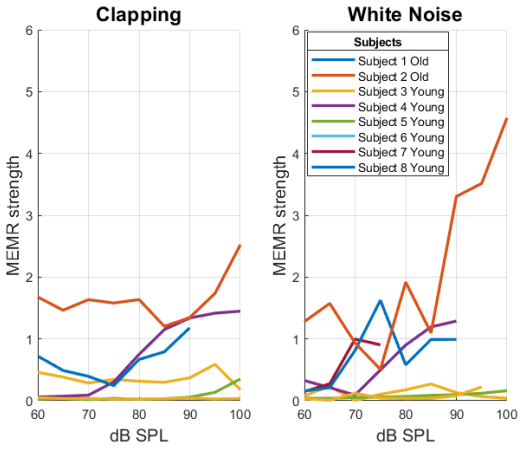

Figure 4: Experiment 2: MEMR strength for two sounds, one natural: "Clapping" and one artificial: "White Noise", for the different participants, each represented in a different colour

Discussion and conclusion

The results in Experiment 1 showed that it is possible to measure MEMR with natural sounds and in addition to this, that the MEMR responses varies from sound to sound. The reason behind this difference in the response has been hypothesized to be related to the spectro-temporal structure of the sound or, alternatively, to some higher level processing. The latter might have been related to the emotional response to the sounds, or the feeling of unpleasantness or loudness, also connected with hyperacusis. The experiment 2 was meant to analyse more deeply this second hypothesis, allowing the participant to always recognise the sound that was presented. However, from the results in experiment 2, we could conclude that it is not possible to have a transposition 1:1 from a stimulation with transient stimuli to one with longer stimuli. The results were, in fact, noisy and, more generally, behaving differently. This might be due either to a technical limitation of the device used or to some other signal registered from the probe. The second result showed from the data in the Experiment 1 is that different sounds at the same level can be perceived with a different loudness and or unpleasantness but being able to elicit the same stimulation. This information can be useful in a clinical setting with participants having problems with sounds, but needing the test. However, this also shows that the presence or absence of an MEMR response is not predictable looking at the perception results neither unpleasantness or loudness. There is clearly a direct correlation with level, as shown in Figure 1, but some other factor must be responsible of the differences among sounds. Finally, the correlation analysis between the MEMR results and both our measures of hyperacusis was not significant, and more surprisingly there is no correlation between the two measures of hyperacusis themselves (CDS and HQ) showing that this phenomenon has a broader complexity and must be analysed further.

Table 1: Hyperacusis and tinnitus assessment experiment1

Participant	Screening		
	HQ	CDS	Tinnitus
1	5	0.84	Y
2	12	11.972	-
3	31	33.41	Y
4	2	37.43	-
5	10	25.33	Y
6	15	19.15	-
7	15	64.00	-
8	14	6.82	-
9	19	13.60	-
10	15	1.49	-
11	15	33.60	-
12	12	9.83	-
13	21	46.99	-
14	25	40.95	Y

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