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Effects of Auditory Selective Attention on Chirp Evoked Auditory Steady State Responses

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Abstract— **Auditory steady state responses (ASSRs) are frequently used to assess auditory function. Recently, the interest in effects of attention on ASSRs has increased. In this paper, we investigated for the first time possible effects of attention on ASSRs evoked by amplitude modulated and frequency modulated chirps paradigms. Different paradigms were designed using chirps with low and high frequency content, and the stimulation was presented in a monaural and dichotic modality. A total of 10 young subjects participated in the study, they were instructed to ignore the stimuli and after a second repetition they had to detect a deviant stimulus. In the time domain analysis, we found enhanced amplitudes for the attended conditions. Furthermore, we noticed higher amplitudes values for the condition using frequency modulated low frequency chirps evoked by a monaural stimulation. The most difference between attended and unattended modality was exhibited at the dichotic case of the amplitude modulated condition using chirps with low frequency content.**

I. INTRODUCTION

Over the last years, auditory steady-state responses (ASSRs) have been commonly used for objective audiometry purposes and still the controversy wether they are also good for monitoring states of anesthesia [1], [2]. ASSRs, which are in the category of auditory middle latency response, where firstly reported by Galambos et al. [3] who collected the potentials by using clicks and tone bursts at different repetition rates. Maximum ASSR amplitudes are obtained when the stimuli have repetition rates near to 40Hz. In [4], the authors evoked ASSRs using different chirp stimuli in an attempt to compensate the cochlear traveling wave delay. Their results revealed a shorter detection time of ASSRs for chirp stimulations compared to click stimulations, and suggested the possibility to replace clicks for chirps in the further acquisition of ASSRs. In other studies, the effect of attention on ASSRs has also been investigated. For instance, Ross et al. [5] as well as Gander et al. [6] and Saupe et al. [7] combined visual and auditory modalities. The authors of [5] applied 40Hz amplitude modulated tone bursts to evoke ASSRs, which from time to time included a second stimulus and differed from the modulation frequency of the standard stimulus and was used as a target stimulus. They concluded that significant attention effects on ASSRs amplitude were more dominant for the left hemisphere. Also, the study reported in [8] using amplitude modulated tones resulted in larger attention effects during dichotic stimulation conditions. In [9], the authors investigated the effect of attention on auditory middle latency responses using low frequency chirps (1-120Hz). In these experiments the subjects had to attend to the sound (attended condition) or to read book (unattended condition). Results showed differences on the lower energy of the response in the reading condition. Bidet-Caulet et al. [10] investigated the electrophysiological representation of concurrent sounds in the human auditory cortex. The results of their study revealed that stream selection of concurrent sounds would not only enhance the neural activity of the relevant sound, but also reduce the neural representation according to the irrelevant information in the auditory cortex. So far, little is known about the generators of the ASSRs, which is an important fact for studying the effects of attention on these responses. Some authors suggested, that the 40 Hz Steady-State-Responses are mainly generated in cortical areas, whereas higher modulation rates are more related to the level of the brainstem [11]. From the point of view, that in selective attentional processes the cortex has to be involved in order to direct the attention to a specific auditory message, only effects should be examined in the 40Hz ASSRs. However, attention effects were also observed by using higher modulation rates [9]. Thus, in this paper we investigate attention effects in a wide modulation rate range by using chirps. For that purpose we collected ASSRs by using amplitude modulated and frequency modulated chirp paradigms. The constructed chirps had a duration of 25ms, and different paradigms were generated using chirps with a low and high frequency content, respectively. Also, stimulations were presented in a monaural and dichotic modality. All the developed paradigms, were tested two times on each subject, in an attended and an unattended condition.

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II. METHODOLOGY

A. Stimuli Generation

Chirps creation: The stimuli used for the generation of the ASSRs were trains of chirps either of low or high frequency content, which were also amplitude modulated or frequency modulated, as explained in detail later. Each of these conditions contained standard and deviant chirps, which difference lies on the instantaneous frequency function used to generate the chirp. Such functions could be based on a fitted or a linear function, if they were standard or deviants, respectively. The low frequency chirps covered a frequency range of 100–250Hz, while the high frequency chirps spanned 250–2000Hz. For the construction of the chirps we used the following equation, as in [12]:

$$S(i,t) = \sin(\Phi(f) - \Phi(fo)) \quad (1)$$

where Φ represents the instantaneous frequency functions, which were in turn the inverse functions of the time delay functions defined as: (1) $\tau = \rho \cdot (f+\alpha)^{-\varsigma} + k$ for the fitted chirps, where ρ=35, α=100, and ς=0.656 and 0.540 for the low and high frequency chirps respectively; and (2) $\tau = \kappa \cdot f + \varrho$ for the linear chirps, where κ=1.046e-6 and ϱ= 0.0251 for the low frequency chirps and κ=1.402e-5 and ϱ=-0.0035 for the high frequency chirps. All chirps were calculated in order to have a total duration of 25ms, i.e., a repetition rate of 40Hz. Also, extra initial phase values were introduced in order to make sure that the chirps started in zero.

Paradigm Generation: After the generation of the chirps, trains of deviants and standard chirps were created, each train consisted of 10 chirps. Next, paradigms with a duration of approximately 5 minutes were constructed using a sampling frequency of 44.1kHz. Each paradigm consisted of 90% standard chirps and 10% deviant chirps. The deviant chirps were presented with a probability of occurrence of 10% and were placed in a randomized in order to maximize the entropy of the experiment. Finally 4 paradigms were generated: AMLF: amplitude modulated low frequency chirps, AMHF: amplitude modultated high frequency chirps, FMLF: frequency modulated low frequency chirps, FMHF: frequency modulated high frequency chirps. The frequency modulated chirps were calculated as shown in Eq.1, whereas the amplitude modulated chirps were calculated by multiplying the same Eq. by a carrier frequency fc, which was 5kHz for our measurements. All already presented and further calculations, as well as the generation of the sound files were accomplished by using software for technical computing (MATLAB–Simulink, MathWorks Inc., USA). The calibration was achieved by measuring the SPL level of each chirp. For that purpose, a sound level meter (type 2250, Brüel & Kjær, Denmark) measured the L_{Zeq} via a prepolarized free field $\frac{1}{2}$" microphone (type 4189, Brüel & Kjær, Denmark) connected to an artificial ear (type 4153, Brüel & Kjær, Denmark). The artificial ear was simultaneously coupled to the headphones (HDA–200, Sennheiser, Germany) while reproducing the respective chirps. All paradigms were presented at an intensity level of 65 dB SPL.

Subjects, Data Acquisition: In the experiments 10 volunteers participated (mean age 26.6±3.34years; 4f/6m) with no history of hearing problems and normal hearing thresholds (below 15dB HL), checked by an audiogram carried out prior to the measurements. After a detailed explanation of the procedure, all subjects signed a consent form. Next, Ag/AgCl-electrodes were attached at the mastoids, vertex and upper forehead. Electrodes impedances were always below 5kΩ. The ASSRs were acquired with a biosignal amplifier (gUSBamp, g.tec, Austria) using a sampling frequency of 4.8kHz. Further, the signals were filtered using (1) a bandpass-filter in the range of 10-100Hz, and (2) a notch filter to remove 50Hz. Movement artifacts were removed by an amplitude threshold of 50μV.

TABLE I
CONDITIONS TESTED

Stimulation Conditions & Task	Paradigms
Monaural (MO) & unattended	AMLF, AMHF, FMLF, FMHF
Monaural (MO) & attended	AMLF, AMHF, FMLF, FMHF
Dichotic (DI) & unattended	AMLF, AMHF, FMLF, FMHF
Dichotic (DI) & attended	AMLF, AMHF, FMLF, FMHF

Experimental paradigms: After electrodes placement, subjects were instructed to lay on a bed, close their eyes and to ignore the stimuli, the same measurements were repeated later and the subjects were this time instructed to detect always deviant sounds. The order of the measured conditions was randomized for each subject. Due to the long time it would require to collect all data from a single subject, experiments were performed in 2 (50min) sessions. On the first session either the amplitude modulated conditions or the frequency modulated ones were performed and on the second appointment the corresponding missing part was collected. A total of 16 conditions were tested, see Table I.

For the monaural cases the right ear was always stimulated, and for the dichotic conditions, stimulation was presented on both ears, here the sound for each ear was delayed from the other one in order to avoid simultaneous stimulation of the deviant in both ears simultaneously.

Postprocessing: After acquisition of the ASSRs, the individual responses were sorted into a matrix. Then, the Fourier transform of the time domain signals was also calculated.

III. RESULTS AND DISCUSSION

A total of 4800 sweeps were collected for each subject and condition. The Fig. 1 shows the mean time domain results of all the tested conditions. For each condition the unattended and attended waveforms, evoked by the monaural and dichotic modality, are illustrated. Note, that the maximum amplitude of the first peak of the attended conditions are in general larger than their corresponding unattended conditions.

In Fig. 2, the mean of the maximum amplitudes over the 10 measured subjects for each condition are shown for the time domain signals. These maximum values were taken from the first peaks of the time domain signals. In contrast to the general tendency, that the peak to peak amplitudes are larger for the attended condition, Fig. 2 shows for the condition FMHFDI a higher amplitude for the unattended condition in the time domain. The biggest difference between maximum amplitude of the attended and unattended modality can be seen at the AMHFDI condition. Furthermore, the largest maximum amplitude is noticeable for the FMLFMO condition. The smallest amplitude values were noticeable for the AMLFMO and AMLFDI.

The percental differences between the attended and unattended paradigms for the mean peak to peak amplitude

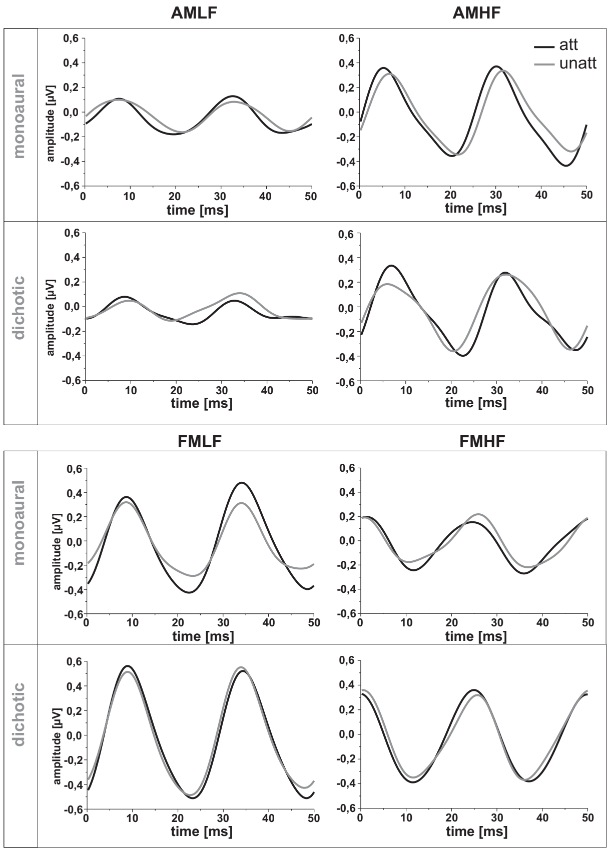

Fig. 1. Grand average over all the subjects of the time domain ASSRs, for all the 16 tested conditions. Gray lines show the corresponding results for the unattended conditions, whereas black lines showed the results for the attended conditions.

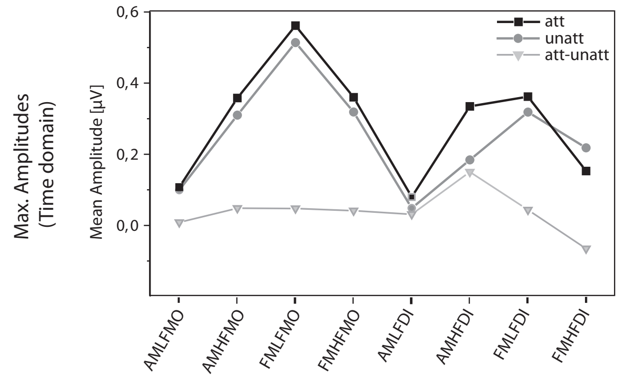

Fig. 2. Mean of the maximum amplitudes for all tested conditions in the time domain. Black line, shows the results for the attended condition, the dark gray line shows the results of the unattended conditions, and the light gray line shows the difference between both conditions.

of the time domain is shown in Fig. 3. In general, the differences of the mean peak to peak amplitudes are in the range of 10 to 15% for the following stimulation conditions: FMHFMO, FMLFMO and AMHFMO. For the monaural case of the condition AMLF the difference of the attended and unattended paradigm is the smallest (4%). In contrast, the dichotic condition of AMLF is characterized by the biggest difference (36%).

The Fig. 4 shows the individual results of the peak to peak amplitude values of the time domain signals, of the first positive and negative waves, for all the monaural and dichotic cases. The black bars correspond to the attended conditions, whereas the gray bars correspond to the unattended ones. Additionally, the means and standard deviations are reported. Note that the averaged peak to peak amplitudes for the attended condition are in general larger than the one for the unattended condition.

For the monaural and dichotic cases it can be seen that the results of the AMLF unattended condition have the smallest amplitudes, which had a mean peak to peak amplitude of 0.384 μV and 0.265 μV, respectively. The FMHF attended condition showed the largest peak to peak amplitude (1.308 μV) at the monaural case, whereas the largest amplitude at the dichotic case was obtained at the AMHF attended condition. Furthermore, there is an amplitude enhancement of the frequency modulated cases for the monaural conditions noticeable.

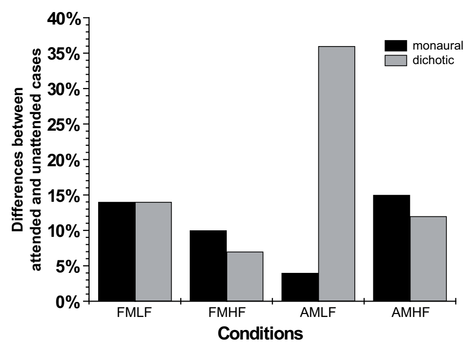

Fig. 3. Percental differences between the attended and the unattended paradigms of the grand average over all the subjects of the time domain ASSRs, for all the 4 tested conditions. Black bars show the corresponding results for the monaural stimulus presentation, whereas grey bars show the results for the dichotic stimulus presentation.

The amplitude values of the dichotic stimulation paradigms are in the same range as the values achieved by using the monaural stimulation. In comparison to the monaural stimulation, a decrease of the amplitude values of the FM to the AM conditions as well as a reduction of the amplitude of the LF compared to the HF modulation could not be observed for the dichotic stimulation. Despite the small mean peak to peak amplitude value of the dichotic AMLF condition of $0.416\mu V$, the largest difference between attended and unattended condition of 36% is noticeable.

IV. CONCLUSIONS AND FUTURE WORK

In the present work, we analyzed possible effects of attention by using chirp based paradigms to evoke ASSRs. For this purpose, specific low and high frequency chirps were designed in order to cover a wide modulation range. This was done due to the fact, that results in literature are still controversial regarding the attention effects on the ASSRs.

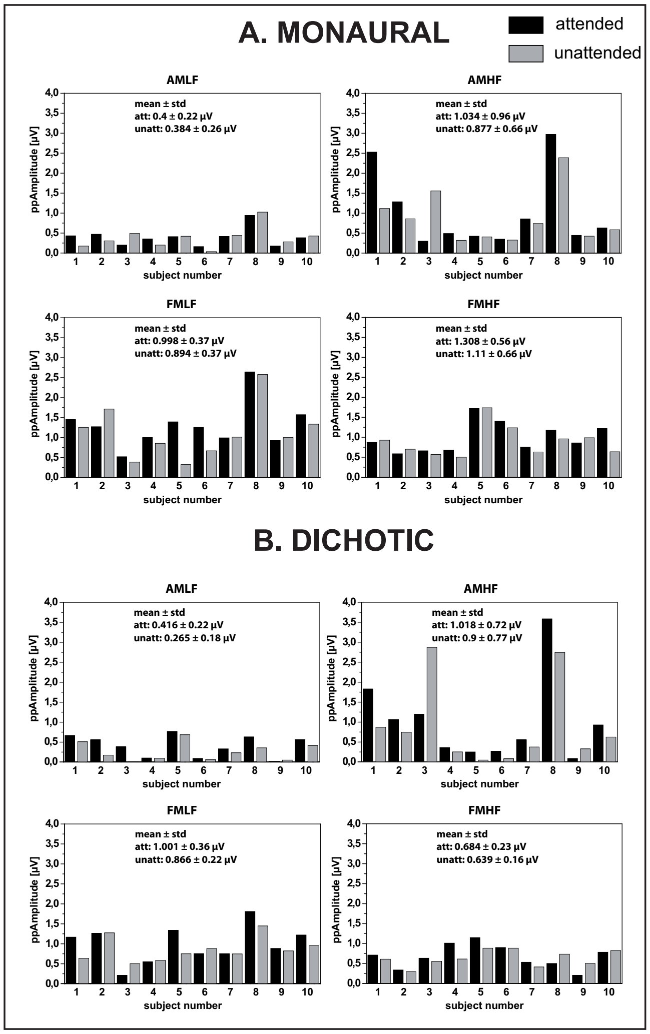

Fig. 4. Individual results of the peak to peak amplitude values of the time domain signals, of the first positive and negative waves, for all the monaural (A) and dichotic (B) cases. The black and gray bars correspond to the attended and unattended conditions, respectively. Also, the means and standard deviations are also reported.

Thus, in this paper we wanted to investigate attention effects in a wide modulation rate range by using chirps.

The paradigms were presented monaurally as well as dichotically in an attended and unattended modality. In general, we found enhanced amplitudes for the attended conditions in the time domain analysis. The highest amplitudes were visible for the condition using frequency modulated low frequency chirps with a monaural stimulation. Nevertheless, the largest percental difference for the mean peak to peak amplitudes in the time domain between the attended and unattended condition could be seen for the dichotic AMLF modality. Based on these results, we conclude that chirps containing a frequency in the range of 100 - 250Hz and which are presented in a dichotic modality enhance the peak to peak amplitudes effected by attention.

For the future work the contralateral recorded data as well as the phase spectrum will be analyzed. Moreover, the gained results of this study will be validated by further measurements using a larger group of subjects. In addition, a comparison to other attention related paradigms using tonebursts as stimuli should be made. Furthermore, the dichotic stimulation and a binaural stimulation had to be compared to examine their effects on attention.

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