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# The Perception of Short-time Acoustic Pulses

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**ABSTRACT**

**The subject of this research is to assess the duration time of the short time acoustic pulses with an Gaussian envelope and duration time less than 20 ms. ITwo groups of people took part in behavioural tests: musicians and non-musicians. Observations indicates that the impression caused by the short time acoustic pulse depends on the duration time of that pulse. The aim of this study is to examine the difference limen between the heard duration time and the actual duration time. It turns out that the dependence of differences in the duration times bases on the Weber-Fechner law. Moreover, the research in an anechoic chamber allows us to make a measurements using an artificial ear (which is a part of an artificial head) of the short-time acoustic pulses not only basis on people's answer but also on electro-mechanical impulse responses. It is surprising that, despite physical restrictions, humans associate some effective pitch to millisecond pulses up to about 20 ms.**

**Keywords:** Short-time pulses, perception, psychoacoustic, Weber-Fechner Law, behavioural tests
**I-INCE Classification of Subject Number:** 79

## 1. INTRODUCTION

Ernst Heinrich Weber and Gustav Theodor Fechner define the dependence between the actual change in a physical stimulus and the perceived change. The formulate states: *Simple differential sensitivity is inversely proportional to the size of the components of the difference; relative differential sensitivity remains the same regardless of size* [1]. This means that perceived change in stimuli is proportional to the initial stimuli. In case of short time acoustic pulses the law is fulfilled when difference limen (just perceptible difference) is proportional to the relative change of the stimuli.

Short time acoustic pulses can be distinguish using a pitch or a timbre. The timbre also known as a tone colour depends on the spectrum: harmonics, overtones, subharmonics etc. Thanks to the timbre the human hearing system is able to distinguish the difference between different type of instruments or voices which isn't tough but if it comes to sounds lasting less than 20 ms there are some difficulties. During behavioural tests some people could not notice the difference between the pitch and the timbre which was relevant to the short duration time of pulses.

The pitch of the sound is related (logarithmic relation) with the periodicity, i.e. the frequency of the signal: the higher the frequency, the higher the pitch of the sound. However, the uncertainty principle (Heisenberg [2] as used in quantum mechanics, or Gabor [3] in signal processing), states that it is impossible to measure the energy (frequency) and duration time simultaneously with the infinite measurement accuracy [1]. In the realm of acoustic pulses as perceived by human hearing it would mean that too short pulses cannot produce a sensation of pitch, the latter being represented by a logarithm of frequency.

## 2. MATERIALS AND METHODS

The software used during behavioural tests had to verify whether participant can hear the difference between two sounds played one after another. Participants with some musical education noticed the difference limen in the pitch and the timbre, and participants without any musical experience checked the first difference which they observed without identifying any difference between the pitch or the timbre. The first sound has the width parameter $0.023\ ms < \Delta t < 0.567\ ms$ and the second $(NN + n * d\,\Delta t)/Fs$, where $d\,\Delta t = 0.15/Fs$, $NN$ is the number of a test series. The listener is asked to indicate the pair number $n_l$ for which the sounds appear to be different. The corresponding difference $n_1 * \Delta t/Fs = d_1\Delta t$ is the discrimination limen sought. If the discrimination limen is proportional to the initial width *NN/Fs* then the Weber-Fechner law is satisfied. Behavioural testing was held in controlled conditions where each participant had the same parameters tools: computers and headphones.

The tests with artificial head phantom in the anechoic chamber and the mathematical basal membrane models were prepared [4]. The head has been tested in an anechoic chamber to eliminate reverberation and environmental noises. The series of the sounds have been recorded in two different test configurations: loudspeaker - microphone; to examine the physical properties of the generated signals and the loudspeaker - artificial head; to check the physiological response of the human hearing system. All the sounds have been normalised to the amplitude. Spectral plots are obtained using Fourier transform. The first experiment that proves the cochlea is an analyser of the spectrum has been performed by [5]. The sounds were played through the loudspeaker in placed at the distance of 1 m from the phantom (Fig 1). The generated sounds were recorded by the microphone in the anechoic chamber. Then, the recorded sounds have been used as an input to the mathematical basal membrane models and have been compared with the results from the phantom [6].

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*Figure 1. The artificial head in the anechoic chamber. The loudspeaker is the only source of the sound.*

## 3. RESULTS

The difference limen test has been repeated with a broad group and shows that, the musical education has an impact on the short time acoustic pulses perception. The results obtained from the tests of the musician group for the just perceptible difference (difference limen) perceived as a change in the pitch and in timbre are presented in the Figure 2 and 3, respectively. The musicians have been able to distinguish difference limen in the effective pitch of short pulses and in the timbre. The just perceptible difference in the pitch reported by the musicians increases proportional to the duration of the reference sound. This relation is Weber Fechner law shifted by the constant value [7].

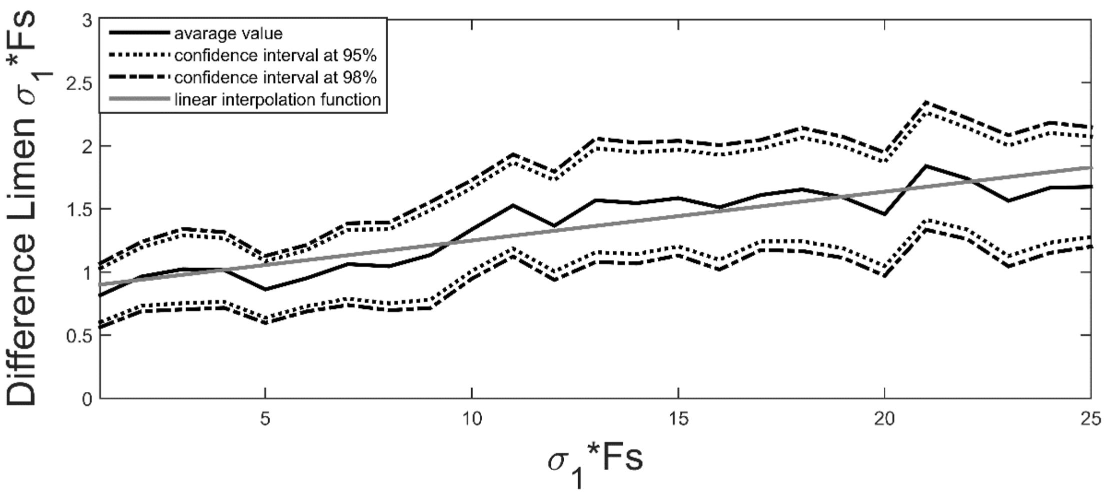


*Figure 2. Just perceptible difference (difference limen) in the pitch (averaged over each reference) – black solid line. Black dotted and dashed line is confidence interval at 95% and 98% respectively. Grey solid line represents the linear fitting function Diff. lim. $\sigma_1 Fs = 0.04\ \sigma_1 Fs + 0{,}86$ with $R^2$ equal to 0.83.*

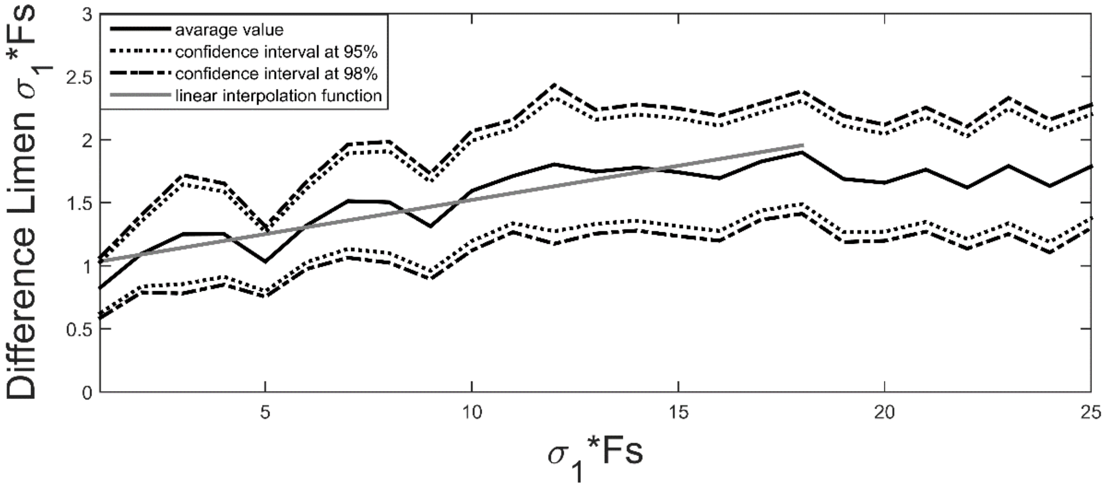


*Figure 3. Just perceptible difference (difference limen) in the timbre (averaged over each reference sound) – black solid line. Black dotted and dashed line is confidence interval at 95% and 98% respectively. Grey solid line represents the linear fitting function between σ = 1/Fs and 18/Fs: Diff. lim.* $\sigma_1 Fs = 0.05\ \sigma_1 Fs + 0.98$ *with* $R^2$ *equal to 0.85.*

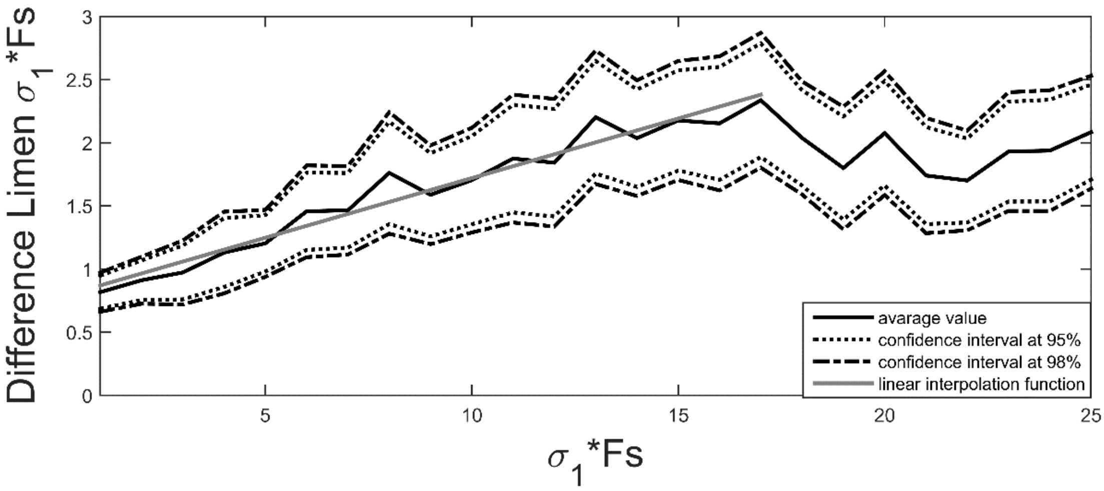


*Figure 4. Just perceptible difference averaged over each reference sound for the non-musicians group – black solid line. Black dotted and dashed line is confidence interval at 95% and 98% respectively. Grey solid line represents the linear fitting function between σ = 1/Fs and 17/Fs: Diff. lim.* $\sigma_1 Fs = 0.09\ \sigma_1 Fs + 0.78$ *with* $R^2$ *equal to 0.96*

Figure 4 shows the just perceptible difference reported by the non-musicians group obtained from the pilot tests [7].

General observations on the working modes of the tested persons are as follows. The musicians noticed the differences between sounds faster and with a higher accuracy. This corroborates observations of ref. [8]. In addition, the musicians are better in memorizing the sounds and for that reason they could use their memory to compare the pulses with better result than non-musicians. [9,10]. The reaction of musicians was the faster, the larger was the difference in the duration time of the pulse in some analogy with the previous studies [11,12]. Just noticeable difference in the pitch of the short acoustic pulses, reported by the musicians, presents a linear tendency and increases with the duration of the reference sound in the pair. The results are well linear in the range of

1 to 25 $\sigma_1$Fs. It is state that the Weber-Fechner law is fulfilled in its generalized form, i.e. the difference limen for the duration time of a Gaussian pulse is an increasing linear function of the duration time itself. This is, however, not proportionality as in the generic Weber-Fechner law. The linear fitting function is shifted to the 0.86, and in consequences this is not a typical Weber Fechner law. The same mechanism is seen in the difference limen results for non-musicians and difference limen of the timbre for musicians. Yet, a linear increase in the difference limen occurs only for pulses with $\sigma$ in the range of 1/Fs and 18/Fs and 1/Fs and 17/Fs of results for musicians reported difference limen of the timbre and results for non-musicians, respectively. This means, that the generalized Weber Fechner law seems to be fulfilled in such ranges of $\sigma_1$ to the reference sound. However, the linear fitting functions are shifted by the 0.98 and 0.78 for musicians reported difference limen of the timbre and non-musicians, respectively.

The effective pitch generally increases with the decrease in the duration time. Fig 5. shows the result for the Gaussian pulses (Gaussian envelope itself). The effective pitch falls with increasing the duration time of Gaussian pulses. The Effective Pitch is not only the physical mechanism [13-17]. As we can see, the results obtained from difference limen behavioural test, and from anechoic chamber (false head comparing to the real head) shows the existence of the effective pitch. Presumably, what is responsible for the effect is not only the physics of sound but also the physiology of the hearing. [18-21]

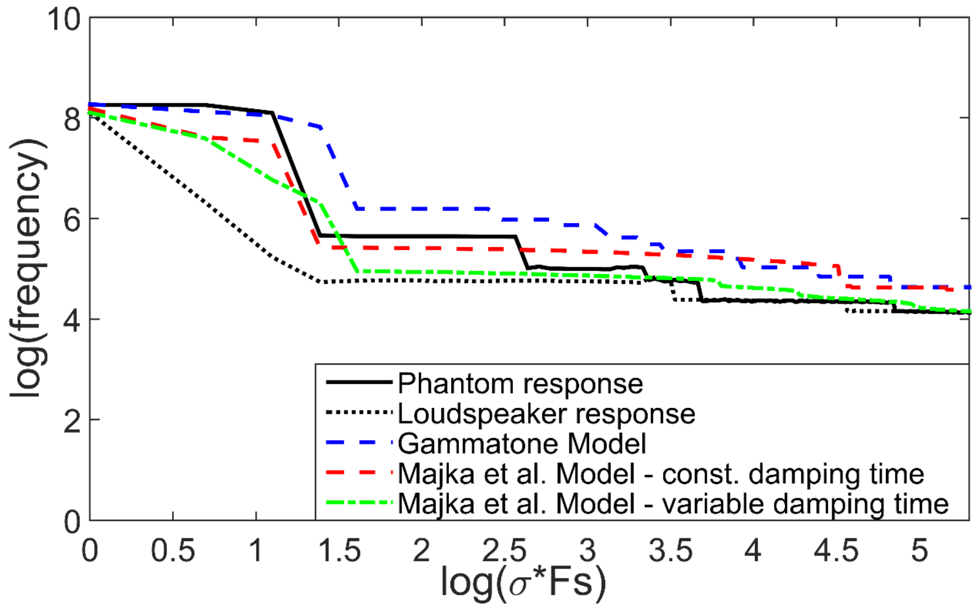


*Figure 5. Comparison of 3 basal membrane models for Gaussian signals with the mode of the measured spectrum. Majka et al. models described in [22], Gammatone model described in [23].*

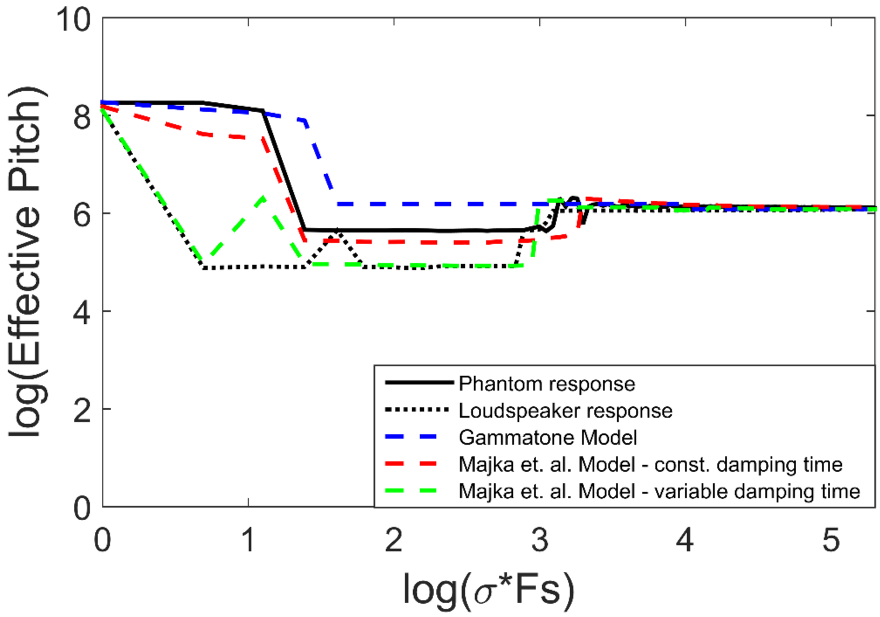


*Figure 6. Comparison of 3 basal membrane models for cosine signals with the mode of the measured spectrum. Majka et al. models described in [22], Gammatone model described in [23].*

The obtained Gaussian and cosine signals are distorted by the loudspeaker membrane. Fig. 6 shows a Gaussian and cosine pulses and the loudspeaker responses to the proposed signals recorded in preliminary measurements. Significant distortion is visible in case of the Gaussian envelope itself. An auditory sensation which is an Effective Pitch must be undoubtedly related to such distortions.

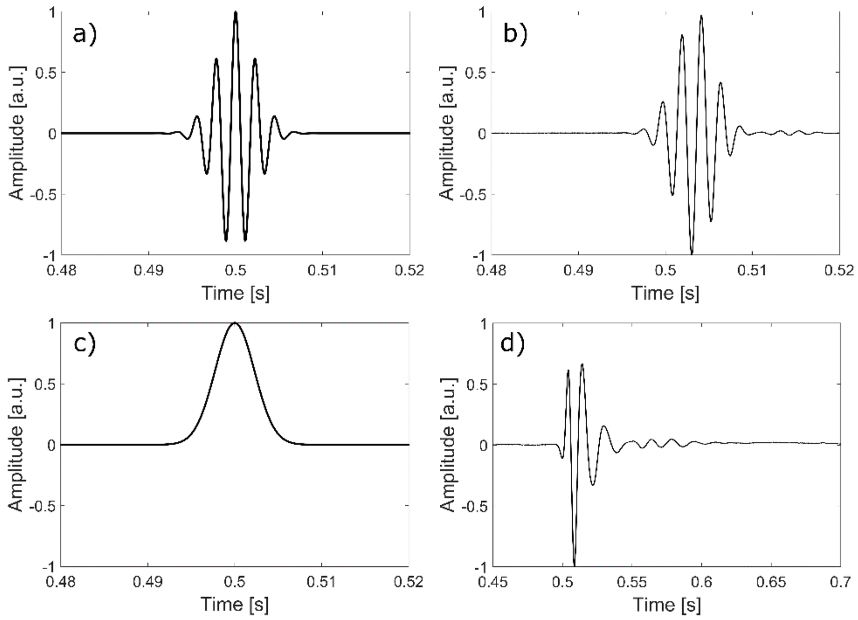


*Figure 7. MatLab generated signals and loudspeaker response signals for pulses with duration time equal to 13.60 ms. (a) input cosine signal, (b) output cosine signal, (c) input gaussian signal, (d) output gaussian signal.*

In the mathematical models of the basal membrane the original signals from the behavioural tests should be used. Only using the real recorded Gaussian pulses in the models we will be able to reproduces the mechanisms responsible for the productions of the Effective Pitch.

## 4. CONCLUSIONS

Participants of the Difference Limen test are able to distinguish the difference between two short time acoustic pulses using two features of the sound: the pitch and the timbre. The Weber-Fechner law is fulfiled for the pitch but is not for the timbre for the sounds lasting less than 20 ms. The just perceptible difference based on the observation of musician group in comparison with non musician group seems to be some different things. The models predict the existence of an Effective Pitch and the phantom response confirms it. Considering the answers of selected models and the phantom it is observed that the Effective Pitch of the sound decreases with the increase of the duration time of the pulses.

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