

## Pitch strength for normal-hearing listeners and cochlear-implant users

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### Introduction

According to ANSI [1], pitch can be defined as “that attribute of auditory sensation by which sounds are ordered on the scale used for melody in music” and is rated on a scale from low to high. A different sensation is the pitch strength, which is the topic of the present study. Fastl and Stoll [2] introduced this sensations as follows: “Independent of pitch magnitude, pitch sensations can be labeled as faint pitch or strong (well pronounced) pitch, leading to a scaling of pitch strength”. The main aim of the present study was to investigate to what extent the sensation of pitch strength is preserved when listening through a cochlear implant (CI). A CI is a device that restores hearing in severely hearing-impaired listeners by mimicking the physical frequency-place transformation of the cochlea to a certain extent and directly exciting the auditory nerve with electric pulses.

Using the same signal types as in Fastl and Stoll [2], pitch strength was measured in CI users and, for comparison, in normal-hearing listeners.

### Methods

#### Apparatus

Signals were presented via a loudspeaker in front of the listener. All signals had the same loudness according to the dynamic loudness model [3]. The experiment was controlled via self-written Matlab scripts.

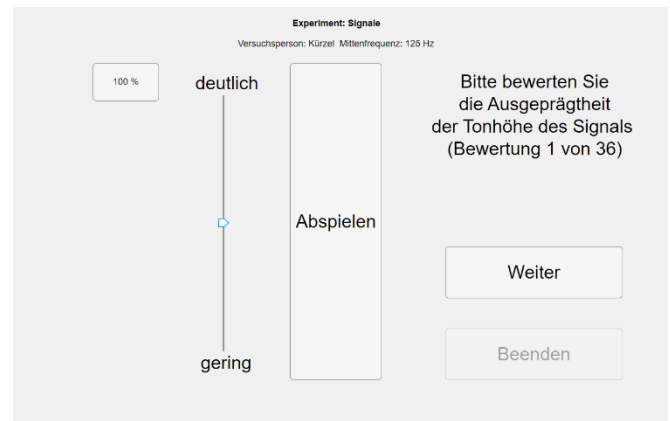
#### Procedure

The experiment consisted of an introduction phase followed by the main experiment. The introduction phase was divided into two parts. In the first part, the listeners were familiarised with the sensation pitch strength by presenting three signals with different pitch strength: a broad-band noise not eliciting any sensation of pitch, a band-pass filtered noise centred at 375 Hz having a bandwidth of 500 Hz with an intermediate pitch strength and a 375-Hz pure tone with a strong pitch. After they listened to these signals, the second part of the introduction phase started. In this part, all signals of one test frequency (see Stimuli for an explanation) were presented in random order. In the subsequent experiment, these signals) were rated using the interface shown in Figure 1. Each signal was rated three times.

#### Stimuli

As in Fastl and Stoll [2], three test frequencies  $f_T$  (125 Hz, 250 Hz and 500 Hz) were used. For each test frequency, twelve signal types were used, resulting in a total of 36 signals. For the test frequency of 125 Hz, all signal types are

shown in Figure 2. The signal types were: Pure tone (s1), a harmonic complex tone consisting of the first (fundamental, frequency  $f_T$ ) to seventh harmonic (s2), a harmonic complex tone similar to the previous stimulus type s2 but now containing all harmonics up to 16 kHz (s3), a band-pass filtered noise with a bandwidth  $\Delta f$  of 10 Hz and a centre frequency equal to  $f_T$  (s4), an amplitude-modulated (AM) tone with a carrier frequency equal to  $4f_T$  and a modulation frequency equal to  $f_T$  (s5), a harmonic complex tone with a missing fundamental consisting of the fourth to 12<sup>th</sup> harmonic of  $f_T$ , i.e. seven components (s6), a band-pass filtered noise similar to the stimulus type s4 but now with a  $\Delta f$  of 100 Hz (s7), a low-pass noise with a cut-off frequency equal to  $f_T$  (s8), a rippled noise with a ripple frequency equal to  $f_T$  (s9), an AM broadband noise with a modulation frequency equal to  $f_T$  (s10), a high-pass filtered noise with a cut-off frequency equal to  $f_T$  (s11) and an AM tone similar to s5 but now with a considerably higher carrier frequency of 5, 6 and 8 kHz for the test frequencies  $f_T = 125$  Hz, 200 Hz and 500 Hz, respectively (s12). In contrast to [2], signals were filtered in the frequency domain by setting the components to zero outside the desired frequency range.



**Figure 1:** Interface of the main experiment. Listeners pressed “Abspielen” (play) to listen to the signal. After signal presentation, they rated this stimulus using the slider. The bottom and top end of the slider were labelled with “gering” (faint) and “deutlich” (strong), respectively. By pressing the button labelled “100 %”, listeners could listen to a pure tone with the test frequency. After rating the stimulus they pressed “Weiter” (continue) to continue with the next stimulus. After the last rating they had to press “Beenden” (terminate) to terminate the experimental run.

#### Listeners

Twenty normal-hearing listeners participated in the experiment. So far, also four cochlear implant users completed the experiment.

