On the pitch strength of bandpass noises

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Abstract

The pitch strength of noises with varying bandwidth has for example been examined by Fastl in [1]. The sounds used had a constant overall level of 50 dB and showed decreasing pitch strength with increasing bandwidth. Additionally pitch strength decreases faster with increasing bandwidth for lower center frequencies than for higher center frequencies.

In this paper, experiments, very similar to those mentioned above, are presented, investigating the pitch strength of bandpass noises. With a constant loudness of 5 sone, possible influences of changes in loudness (resulting from changes in bandwidth at constant overall level) on the perceived pitch strength are avoided. As expected, the corresponding results are pretty much the same as in the reference data by Fastl. Closer looks at the results evoke the assumption that the perceived pitch strength might be depending on the noise's bandwidth relative to the actual critical bandwidth at the noise's center frequency. Thus a second experiment is described to examine the hypothesis of this dependency.

Statistical analysis of the data was done trying to find a significant proof for the hypothesis. Both tests applied did not definitely prove that pitch strength is only dependent on the sound's bandwidth relative to the critical bandwidth at the sound's center frequency.

1. Introduction

The psychoacoustic sensation of pitch gives a measure of as how ”high” or ”low” a sound could be described by a listener. Pitch strength, on the other hand, is a psychoacoustic measure, describing the ability to determine a certain pitch in a sound and thus how strong or clear that pitch can be heard. It has been widely investigated in the literature, e.g. by Fastl and Stoll [2] and Fastl [3]. More noiselike sounds were investigated among others by Fastl [4] or Patterson et. al. [5]. Sometimes the term ”pitch strength” is also described as ”pitch salience” or ”prominence”. Nowadays, in the case of sound quality evaluation, a very similar measure is examined using the term ”tonalness”.

In an early research by Fastl and Stoll [2] the pitch strength of different kinds of sounds was compared. As one might expect, sinusoids have been found to evoke the strongest pitch. Among others, narrow- and bandpass noises have been investigated at different center frequencies showing decreasing pitch strength with increasing bandwidth.

In a later experiment by Fastl [1] the pitch strength of bandpass noises with different bandwidthes was investigated. Again a decreasing pitch strength with increasing bandwidth was found. Additionally it was found that with increasing center frequency the pitch strength decreases more slowly.

In this paper, experiments are described, examining very similar sounds that were kept at a constant loudness instead of a constant overall level. This is done to avoid influences of loudness on pitch strength, as a dependency of pitch strength on level was found in [3] for sinusoids.

2. Pitch Strength and absolute Bandwidth

2.1. Stimuli and Procedure

In close relation to the data by Fastl [1], narrowband noises were chosen as stimuli. Other than in the cited paper, no constant overall level was chosen for the sounds, but a constant loudness. Using the dynamic loudness model by Chalupper [6] the level of each stimulus was adjusted to a calculated loudness of 5 sone, which is significantly higher than the loudness evoked by the sounds used by Fastl, which had a constant overall level of 50 dB. With a bandwidth of 3.16 to 1000 Hz this level corresponds to a loudness of about 2 to 3.5 sone, increasing with bandwidth.

By choosing a constant overall loudness instead of a constant level, effects of loudness on pitch strength, as described in [3] for sinusoids, should be avoided. The center frequencies (arithmetic mean) for the bandpass noises used, were 250, 500, 1000 and 2000 Hz. Testsound duration was set to 0.5 seconds, which, according to [3], should lead to a full perception of pitch strength.

For the experiments the method of magnitude estimation with an anchor-sound was chosen. Thereby pairs of stimuli were presented with pauses of 0.35 seconds in-between. The testsounds used were synthesized using

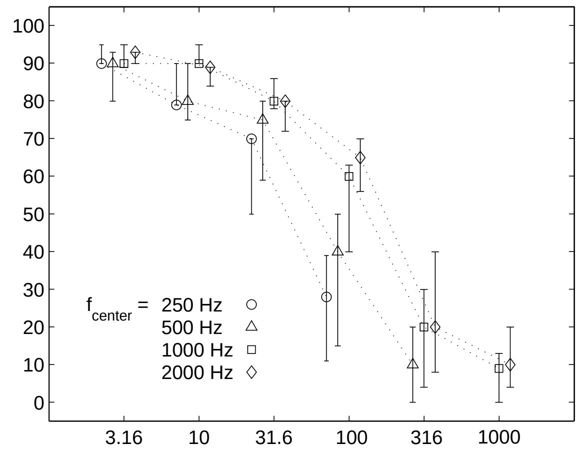

Figure 1: *Results from [1] found by Fastl: Pitch strength of bandpass noises with varying bandwidth relative to the pitch strength of a sinusoid at the center frequency of the testsound.*

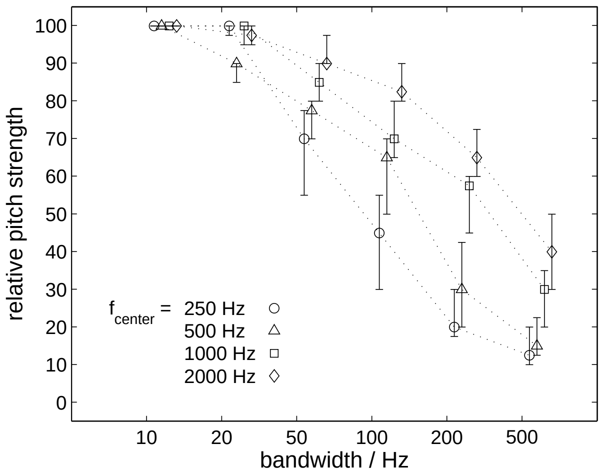

Figure 2: *Results for experiment 1: Pitch strength of bandpass noises relative to the pitch strength of a narrowband noise with a constant bandwidth of 10 Hz at the same center frequency as the testsound. Note that for a center frequency of 250 Hz a bandwidth of 500 Hz actually corresponds to 480 Hz (20-500 Hz).*

single sinusoids of random starting phase with a spectral distance of 1 Hz. The overall bandwidth was set to 10 to 500 Hz except for the lowest center frequency of 250 Hz. Here the bandlimits of the broadest noise were chosen from 20 to 500 Hz, so that in this case the maximum bandwidth was 480 Hz instead of 500 Hz used for the higher center frequencies.

The anchor was chosen as a narrowband noise with a constant bandwidth of 10 Hz symmetrically around the center frequency unlike the sinusoidal anchor used by Fastl in the reference experiment. To avoid spectral broadening, a gaussian modulation with a rise time of 10 msec was applied to all sounds used.

The subjects' task was to judge the pitch strength of the second sound within a pair of sounds relatively to the pitch strength of the first one. So the results show pitch strength values relative to the anchor-sound, which means that a value of 100 does not mean equal pitch strength as a sinusoid, as one might think, but equal pitch strength as the anchor-sound. By presenting pairs of same sounds (anchor vs. anchor), the subject's concentration and reliability were also tested.

Eleven subjects, aged from 21 to 31 years (mean age: 25.3), took part in the experiment. For each subject threshold in quiet was measured to assure normal hearing capabilities.

The experiment itself consisted of 2 runs within each all possible sound pairs were presented in random order for four times. This led to a total of eight judgements per subject for each sound configuration. Little training was given to the subjects as the first five trials in each run were deleted and not used for the statistics. The subjects had no possibility to listen repeatedly to the stimuli pairs in case that they were unsure about their judgement.

2.2. Results

The experimental results are shown in Figure 2 as medians and interquartile ranges. Thereby the median is calculated as median of the median values for each test subject and the interquartiles are calculated as the median of all subjects' interquartile values.

It can be seen that the pitch strength of the sounds decreases with increasing bandwidth and also a dependency on center frequency is appearing. Looking at an absolute bandwidth of 100 Hz, the pitch strength has decreased to a value of about 40 to 80 percent. For this value of bandwidth, the dependency on center frequency is highest for the data found. For a center frequency of 250 Hz, pitch strength has already decreased to about 45 percent relative to the anchor whereas it still has a value of over 80 percent at a center frequency of 2000 Hz.

Overall the pitch strength decreases less for sounds at a center frequency of 2000 Hz, namely it decreases from 100 percent to about 40 percent. The highest decrease is observed for the lowest center frequency of 250 Hz. Here a decrease from 100 percent to about 10 to 20 percent was found.

The data found is very much similar to the results found by Fastl, shown in figure 1, which had to be expected as the sounds were quite similar, except for a level difference and a different anchor-sound. The different anchor is responsible for the fact that pitch strength decreases faster in the reference data than in the actual data.

Looking at the human auditory system as a spectral analyzer, namely a filterbank, it seems obvious, that pitch strength is depending on filter bandwidth in a way that pitch strength is higher when the bandwidth of a sound is small relatively to the filter's bandwidth and that it's decreasing, when the bandwidth of the testsound increases. Taking into account the concept of critical bands introduced by Zwicker ([7], [8]), the hearing system can be described as a set of filters with almost equal filter bandwidths of 100 Hz up to a center frequency of 500 Hz and above filter bandwidth increases approximately linear with a factor of 0.2 times the center frequency.

Looking at the results for a testsound bandwidth of 100 Hz once more, the results seem quite plausible in this context. At a center frequency of 250 Hz the critical band has a bandwidth of about 100 Hz as described above. Thus the testsound has about the same bandwidth as the filter. On the other hand, for a center frequency of 2000 Hz, critical bandwidth has already reached a value of about 300 Hz, which is three times the bandwidth of the testsound and thus the hearing system should be able to detect the signal much more distinct at this higher center frequency.

For several subjects, the resulting curves for 250 and 500 Hz were looking quite similar, which confirms the proposition, that the pitch strength is mainly dependent on the filterbandwidth of the auditory system at the center frequency of a certain testsound. This assumption lead to experiment 2, which is described in the next section.

3. Pitch Strength and Critical Bandwidth

3.1. Stimuli and Procedure

The setup for the second experiment was identical to that for the first one, described in section 2.1, except for the fact that now the bandwidth of the stimuli was chosen relatively to the critical bandwidth at the center frequency. The critical bandwidth was calculated using the formula

$$\Delta f_G/Hz = 25 + 75[1 + 1.4(f/kHz)^2]^{0.69}$$

given by Zwicker and Terhardt in [9].

percent of critical bandwidth	f_{center}/Hz 250	500	1000	2000
5	5.2	5.8	8.1	15.0
10	10.4	11.7	16.2	30.1
20	20.9	23.4	32.4	60.2
50	52.2	58.6	81.1	150.38
100	104.5	117.3	162.2	300.77
150	156.7	175.9	243.3	451.15
200	208.9	234.5	324.4	601.54

Table 1: *Bandwidth (in Hz) of the testsounds used for the second experiment.*

The resulting bandwidths used for the stimuli are shown in table 1. As the critical bandwidth is almost constant below 500 Hz the bandwidth of testsounds at a center frequency of 250 and 500 Hz is almost the identical.

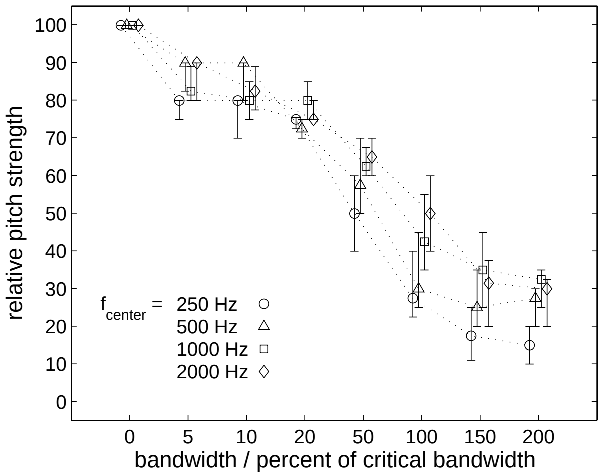

Figure 3: *Results for experiment 2: Pitch strength of bandpass noises with varying bandwidth relative to the critical bandwidth at the center frequency. Pitch strength values are given relatively to the pitch strength of a sinusoid (bandwidth '0' percent) at the same center frequency as the testsound.*

The anchor-sound now was chosen as a sinusoid like in the experiments by Fastl. Synthesis of the stimuli was done in the same way as in the first experiment using same duration and loudness.

Again eleven subjects, of which eight had already participated in the first experiment, took part in the second experiment. The age now ranged from 21 to 57 years with a mean of 28.3 years. For those subjects that did not take part in the first experiment, threshold in quiet was measured.

3.2. Results

The results for the second experiment are shown in figure 3 in the same way as the data for the first experiment was shown in figure 2.

It can clearly be seen that the curves for the pitch strength values of the sounds at different center frequencies are very close to each other now. But still there seems to be a small dependency on the center frequency, especially when looking at the results for noises with a bandwidth of 50 and 100 % of the critical bandwidth. Like in the first experiment, sounds at lower center frequencies have decreased further in pitch strength, for this relative bandwidth, than sounds at higher center frequencies.

The fact that the interquartile regions are mostly overlapping seems to suggest the assumption of pitch strength being only dependent on the relative bandwidth of a stimulus to the actual critical bandwidth. To get a closer look at this, additional statistical tests have been applied to the data found, as described in 4.

4. Statistical Analysis

To verify or reject the stated hypothesis, some significance testing was done. Thereby the hypothesis was tested, whether the results for different center frequencies arise from one and the same entirety. For the tests, the data for each center frequency was compared to each of the other center frequencies for each single subject. This leads to six combinations per subject and with eleven subjects to a total of 66 tested sets of data.

Using a 'Welch-test', the hypothesis could not be rejected for any of the subjects' results at a significancy level of 0.05. But unfortuantely, the hypothesis was proven for all but four combinations when the test was applied to the data from the first experiment. When rising the level of significance to 0.1, the difference grows and for the second experiment, the hypotheses can only be rejected for five combinations compared to 16 results in the first experiment. But still there is a large amount of results in the first experiment seeming to prove the hypothesis. So this test's result seems to be quite weak and so another test was applied.

With a 'Wilcoxon-test', at a significancy level of 0.05, only for seven results in the first experiment the hypothesis could not be rejected, but for the second experiment, the hypothesis could not be rejected for 23 results. But as this is much less than half of the results, these statistical results are not rated as proving the hypothesis.

5. Discussion and Conclusion

As was already mentioned in the results sections (2.2 and 3.2), the dependency of pitch strength on center frequency, as it was found by Fastl in [1] could be reproduced in the experiments described in this paper.

The hypothesis that the pitch strength of bandpass noises is only depending on the noise's bandwidth relative to the critical bandwidth at the noise's center frequency could not be finally proven or rejected using several statistical tests (section 4).

Possible explanations for this fact and shortcomings of the experiments carried out might be the following: narrowband noise is known to produce some 'own-modulation' with an effective modulation frequency of $f^*_{mod} = 0.64\Delta f$ as shown in [10] and [11]. This modulation leads to a more or less perceivable fluctuation strength or even roughness which might disturb the perception of pitch and pitch strength. Another point might be the fact, that the sounds have been synthesized with equal level within the whole bandwidth. Regarding the critical bandwidth as some kind of '3 dB cutoff frequency', the sounds maybe should have had a slightly smaller bandwidth or maybe should have been synthesized using a spectral envelope formed like the critical band filters themselves.

The fact that the critical bands have different bandwidths for each subject, which was not measured during the experiments described above, may play a minor role for the results. As the data results from the judgements of several subjects, the error arrising from different critical bandwidths should be neglectable on the average.

6. Acknowledgments

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