Consonance – Dissonance
Evaluation of Electrical Machine Noise

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Introduction

The noise produced by technical sources, such as electrical drives, often has tonal components which produce a pitch sensation dependent on drive speed or switching frequencies of a power converter. In the case when two machines are working simultaneously at different speeds, each one can have different pitches, evoking a sensation of consonance or dissonance depending on this pitch.

This sensation of consonance-dissonance is well known from music and music sciences. In this work the result of two listening tests are presented, where the sensation of dissonance is not produced by musical instruments but by two electrical drives.

Consonance-Dissonance

The sensation of dissonance is related with the critical band [6], roughness [4] and music perception [6][4] and is often defined with adjectives like turbid [5] and harsh [7]. The sensation of consonance is treated as the opposite with words like euphony, pleasantness or clearness [7].

Plomp [8] writes "musicians make a clear distinction between pleasantness and consonance"… "for naive subjects, however, consonance and pleasantness are much more similar concepts".

Listening Test

A listening test with 18 listeners was done using synthesized machine sound as stimuli, based on recordings of real machine noise. For the stimuli, the noise from two machines turning at different speeds was added. Also a background noise with some roughness and modulation was added to all the stimuli to make it sound more realistic.

28 Stimuli (duration of 3 seconds) were presented to each listeners two times in random order.

This was done with two different methods for each listener:

- Category Partition (CP) [1][9] with five main categories (labelled from not all dissonant to very dissonant) each, subdivided with 10 numerical values for a more precise answer and
- Absolute Magnitude Estimation (AME) [1][9] where the listener gives any numerical answer that represents the perceived dissonance.

Stimuli

The stimuli consist in harmonic complex tones with peaks at different frequencies as indicated in Table 1. A second harmonic complex tone has a different fundamental and as a consequence a different pitch. The level of the noise can have one of two levels.

File	Freq (Hz)	Motor (Amplitude)								Semi-tones	Gear (Amplitude)								Noise Ampl
1	200	4	4	3	6	10	0	10	6	5	4	4	3	6	10	0	10	6	high
2	200	4	4	3	6	10	0	10	6	2	4	4	3	6	10	0	10	6	high
3	200	4	4	3	6	10	0	10	6	1	4	4	3	6	10	0	10	6	high
4	200	4	4	3	6	10	0	10	6	0	4	4	3	6	10	0	10	6	high
5	200	4	4	3	6	10	0	10	6	0	4	4	3	6	10	0	10	6	low
6	200	4	4	3	6	10	0	10	6	-1	4	4	3	6	10	0	10	6	high
7	200	0	4	3	6	10	0	10	6	-1	0	4	3	6	10	0	10	6	high
8	200	10	4	3	6	10	0	10	6	-1	10	4	3	6	10	0	10	6	high
9	200	4	4	3	6	10	0	10	6	-2	4	4	3	6	10	0	10	6	high
10	200	0	4	3	6	10	0	10	6	-2	0	4	3	6	10	0	10	6	high
11	200	4	0	3	6	10	0	10	6	-2	4	0	3	6	10	0	10	6	high
12	200	10	4	3	6	10	0	10	6	-2	10	4	3	6	10	0	10	6	high
13	200	0	0	3	6	10	0	10	6	-2	0	0	3	6	10	0	10	6	high
14	200	0	0	3	6	10	0	10	6	-2	0	0	3	6	10	0	10	6	low
15	200	4	4	3	6	10	0	10	6	-4	4	4	3	6	10	0	10	6	high
16	200	4	4	3	6	10	0	10	6	-5	4	4	3	6	10	0	10	6	high
17	200	4	4	3	6	10	0	10	6	-5	4	4	3	6	10	0	10	6	low
18	200	0	4	3	6	10	0	10	6	-5	0	4	3	6	10	0	10	6	high
19	200	4	0	3	6	10	0	10	6	-5	4	0	3	6	10	0	10	6	high
20	200	0	0	3	6	10	0	10	6	-5	0	0	3	6	10	0	10	6	high
21	200	0	0	3	6	10	0	10	6	-5	0	0	3	6	10	0	10	6	low
22	200	4	4	3	6	10	0	10	6	-6	4	4	3	6	10	0	10	6	high
23	200	4	4	3	6	10	0	10	6	-7	4	4	3	6	10	0	10	6	high
24	200	4	4	3	6	10	0	10	6	-7	4	4	3	6	10	0	10	6	low
25	200	4	4	3	6	10	0	10	6	-11	4	4	3	6	10	0	10	6	high
26	200	4	4	3	6	10	0	10	6	-12	4	4	3	6	10	0	10	6	high
27	200	4	4	3	6	10	0	10	6	-12	0	4	3	6	10	0	10	6	high
28	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	high

Table 1: Description of the stimuli used in both listening tests.

Results

The dissimilitude (distance) between the two answers for each stimulus can be calculated. Two listeners had a high mean distance between both answers, and this for both tests, so they were not considered for further analysis. Also another listener who had a very monotone answering strategy in the AME was taken out.

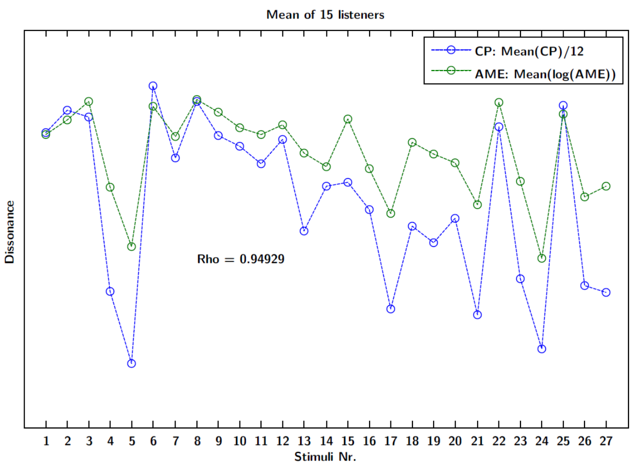

Figure 1: Mean of both tests. The result of CP was scaled to permit a representation in the same figure. The correlation coefficient between both curves is ρ = 0.95.

Since the results from a AME were ratio scaled the geometric mean was used instead of the arithmetic mean.

Analysis of the Result

In Figure 1 it can be seen that stimuli 4 and 5, 23 and 24 and 26 and 27 have a lower dissonance than the stimuli around. These 6 stimuli have a "consonant" frequency ratio (0 semitones, 7 semitones and 12 semitones) confirming what is known from music and harmony and the results presented in [4][6][8].

The reduction of dissonance from stimulus 4 to 5, 16 to 17, 20 to 21 and 23 to 24 shows the influence of the level of the background noise. Between these pairs of stimuli, the only parameter that changed was the level of the background noise.

Psychophysics

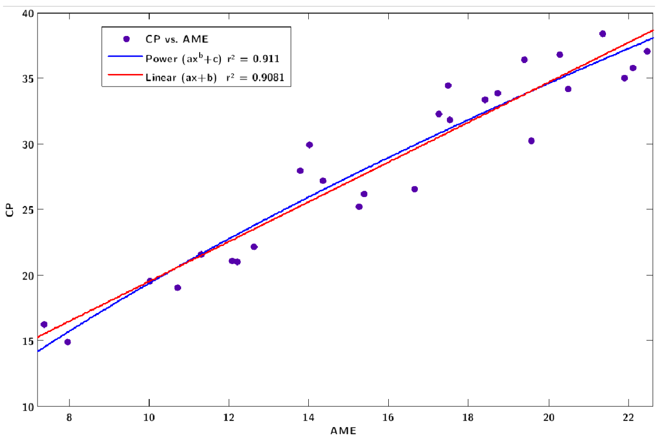

Figure 2: Plot of the mean of CP vs. geometric mean of AME and two fitted curves using a power and a linear function. The goodness of fit is similar in both cases.

The relation between both test methods (CP and AME) should be a power function, since CP has equal distances between the categories and AME gives a ratio scaled values, if the sensation is on a prothetic continua [1][9]. In [10] the result of an experiment similar to this one is presented, where the same set of stimuli was used with a Unipolar Category Scale and a Magnitude Estimation with reference. The goodness of fit of a power function between both results is $r^2 = 0.94$ and $r^2 = 0.89$ for a linear function.

A plot of the mean answers from both tests is shown in Figure 2 with the AME on the x-axis vs. CP on the y-axis.

The range of numbers used in the AME test is not defined by a reference and is free. The distance between the answers of the listeners can be used to make a plot that shows that there are three "groups of answering strategies" in the AME test. This is shown in Figure 3 with three different colours. In Figure 4 a plot similar to Figure 2 is shown, where the three groups are marked with different colours. Also a fitted curve (power function) and the goodness of fit values are shown. The results also could have be fitted with linear functions, but the power function has a better goodness of fit value.

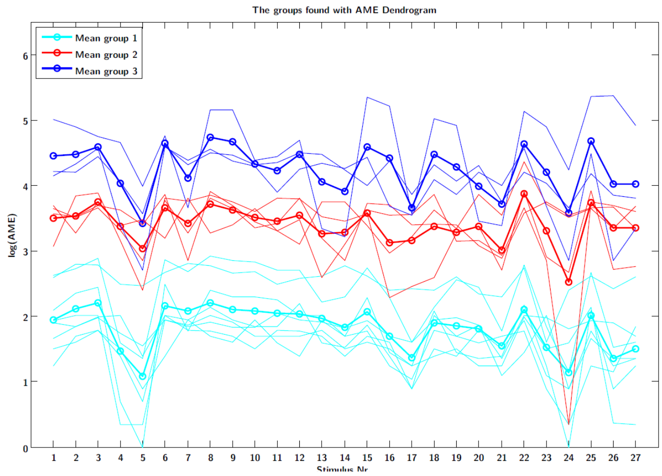

Figure 3: Answers of the 15 listeners for the AME test. Three different groups can be seen. The number range used in the test was different for each group.

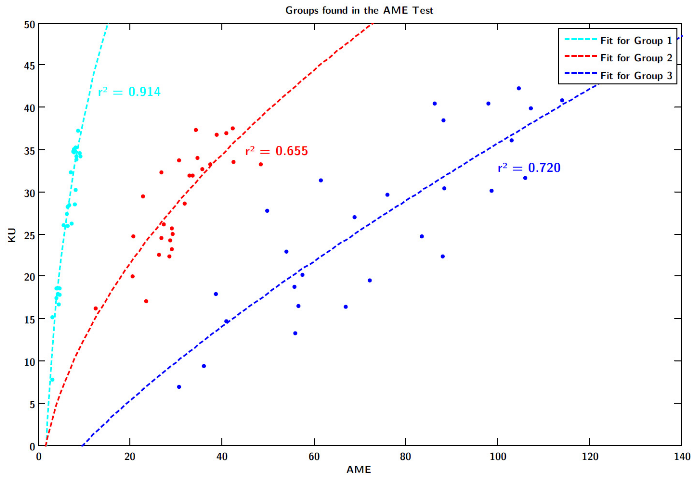

Figure 4: Answers of the 15 listeners for the AME test. Three different groups can be seen. The number range used in the test was different for each group.

Conclusions

From the results of this experiment it can be concluded that there is a statistically significant difference in perceived dissonance if:

- different frequency ratios (i.e. "intervals" or "semitones") are used or if
- the level of the background noise is changed.

The mathematical relation between both methods (CP and AME) for the perceived dissonance of machine noise is not unambiguously defined, since the goodness of fit value for a linear function is not considerable different from the power function.

A closer look into the individual answers shows that three main groups can be founded, which used numerical values in a different way.

It can also be concluded that both tests measured the same parameter, because the "means of the answers" for both methods have a high correlation. This is in accordance with the results from [9][10] in relation on "the use of numbers with Magnitude Estimation experiments" and "the calculation of the mean of the results of the individual listeners".

References

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