Applying Physics Makes Auditory Sense

A New Paradigm in Hearing

The residual pitch and beat phenomena that can be heard in practice by the reader

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Direct presentation of composed sound fragments

as a result of our experiments

This file is a copy of the Appendix II from the booklet:

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A II.1 Introduction

In case you are not able to use the calculation program mentioned in Appendix I, this Appendix II and the associated sound fragments, calculated by us with the program designed by Yves Mangelinckx, provide you with the possibility to listen to the predicted residual pitch and beat phenomena as described in Chapter 3 of this booklet

For each experiment described in Chapter 3 we have filled in the correct frequencies within the calculation program, and composed a sound complex fragment with a ten second duration.

You are invited to download the sound fragments via one of the following websites:

http://www.een-andere-kijk-op-horen.nl/

or

http://www.a3ccm-apmas-eakoh.be/

The fragments are grouped per subject in zipped directories.

In the report of these experiments below as an example the notation:

[Sound E 2 0] refers to the file (E 2 0.wav) in the list of sound fragments

while E 2 corresponds to paragraph 3.2.

A II.2 Experiments

3.2. Pitch perception in incomplete harmonic sound complexes

Experiment 3.2.0

In this Experiment we have filled in the frequencies:

$f_0 = 200$ Hz; $f_1 = 400$ Hz; $f_2 = 700$ Hz and $f_3 = 900$ Hz

you will hear a harmonic tone in the sound fragment:

[Sound E 2 0]

Experiment 3.2.1

To the frequencies in Experiment 3.2.0 we have added:

$f_4 = 99$ Hz or $f_4 = 101$ Hz, with Extra Multiply Amplitude 2

[which is the test signal for pitch determination]

you will hear a beat of 2 Hz in the sound fragments:

[Sound E 2 1] respectively [Sound E 2 2]

[Counting 20 dips during a 10 second sound fragment means 20:10=2 Hz beat]

3.3. Residual pitch perception in enharmonic tone series

Experiment 3.3.0

In the calculation program we have filled in the frequencies:

$f_0 = 1400$ Hz; $f_1 = 1600$ Hz; $f_2 = 1800$ Hz

with that combination you will hear a harmonic tone in the sound fragment:

[Sound E 3 0]

Experiment 3.3.1

In Experiment 3.3.0 we have modified the center frequency from:

$f_1 = 1600$ Hz into $f_1 = 1600.5$ Hz

the triplet becomes:

$f_0 = 1400$ Hz; $f_1 = 1600.5$ Hz; $f_2 = 1800$ Hz

and you will hear the same harmonic tone, but with a 1 Hz beat in the sound fragment:

[Sound E 3 1]

[Counting 10 dips during a 10 second sound fragment means 10:10=1 Hz beat]

Experiment 3.3.2

In Experiment 3.3.0 we have modified the center frequency from:

$f_1 = 1600$ Hz into $f_1 = 1599.5$ Hz

the triplet becomes:

$f_0 = 1400$ Hz; $f_1 = 1599.5$ Hz; $f_2 = 1800$ Hz

and you will hear the same harmonic tone as in Experiment 3.3.0, but again with a 1 Hz beat in the sound fragment:

[Sound E 3 2]

[Counting 10 dips during a 10 second sound fragment means 10:10=1 Hz beat]

3.4. Addition of harmonics and their influence on beat phenomena

Experiment 3.4.0

To the triplet in Experiment 3.3.2 we have added another contribution of two frequencies:

$f_3 = 1200$ Hz; $f_4 = 2000$ Hz

which creates the 5-tone complex:

$f_0 = 1400$ Hz; $f_1 = 1599.5$ Hz; $f_2 = 1800$ Hz; $f_3 = 1200$ Hz; $f_4 = 2000$ Hz

now you will hear a harmonic tone with a 0.5 Hz beat in the sound fragment:

[Sound E 4 0]

[Counting 5 dips during a 10 second sound fragment means 5:10=0.5 Hz beat]

Experiment 3.4.1

To the triplet in Experiment 3.3.2 we have added two frequency contributions:

$f_3 = 1000$ Hz; $f_4 = 1200$ Hz instead of: $f_3 = 1200$ Hz; $f_4 = 2000$ Hz

again you will hear a harmonic tone with a 0.5 Hz beat, however with another timbre in the 5-tone sound fragment:

[Sound E 4 1]

Experiment 3.4.2

To the triplet in Experiment 3.3.2 we have added two other frequency contributions:

$f_3 = 2000$ Hz; $f_4 = 2200$ Hz instead of: $f_3 = 1000$ Hz; $f_4 = 1200$ Hz

again you will hear a harmonic tone with a 0.5 Hz beat, again with another timbre in the 5-tone sound fragment:

[Sound E 4 2]

Remark

In case you find it difficult to distinguish and count a 0.5 Hz beat frequency we can also use, for instance:

$f_1 = 1601$ Hz *or* $f_1 = 1599$ Hz

all beat phenomena will then be doubled in frequency.

For instance the beat in the triplet:

$f_0 = 1400$ Hz; $f_1 = 1601$ Hz; $f_2 = 1800$ Hz

will be heard as 2 H as in the sound fragment:

[Sound E 4 3]

Whilst by adding two extra frequencies:

$f_3 = 1200$ Hz; $f_4 = 2000$ Hz

we can create the 5-tone complex:

$f_0 = 1400$ Hz; $f_1 = 1601$ Hz; $f_2 = 1800$ Hz; $f_3 = 1200$ Hz; $f_4 = 2000$ Hz

and the 2 Hz beat you will hear is changed into 1 Hz in the sound fragment:

[Sound E 4 4]

3.5. Modifying a beat frequency by adding a low frequency stimulus

Experiment 3.5.1

We have filled in the triplet:

$f_0 = 1400$ Hz; $f_1 = 1600.5$ Hz; $f_2 = 1800$ Hz

so you will be able to hear a harmonic tone complex with a beat of 1 Hz in the sound fragment:

[Sound E 5 1]

Experiment 3.5.2

To the triplet in Experiment 3.5.1 we have added the test signal:

$f_3 = 100$ Hz with Extra Multiply Amplitude 2

[which is the test signal for pitch determination]

you can hear that this tone complex – which had a beat of 1 Hz – is changed into a tone complex with much lower timbre and with a 0.5 Hz beat in sound fragment:

[Sound E 5 2]

Experiment 3.5.3

To the triplet in Experiment 3.5.1 we have added the test signal:

$f_3 = 200$ Hz with Extra Multiply Amplitude $\geq \sqrt{2} = 1.4142$

you will hear that the former harmonic tone complex is changed in timbre, however the beat of 1 Hz you hear, isn't changed in the sound fragment:

[Sound E 5 3]

3.7. Is pitch shift in an enharmonic tone complex with equidistant frequencies an illusion?

Experiment 3.7.0

In the first one of this series we have filled in the frequencies of a 7-tone complex:

$f_0 = 1400$ Hz; $f_1 = 1600$ Hz; $f_2 = 1800$ Hz; $f_3 = 2000$ Hz; $f_4 = 2200$ Hz;
$f_5 = 2400$ Hz and $f_6 = 2600$ Hz

which allows you to hear a harmonic tone in the sound fragment:

[Sound E 7 0]

Experiment 3.7.1

To the 7-tone complex in Experiment 3.7.0 we have added the twin-tone contribution:

$f_7 = 201$ Hz; $f_8 = 402$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

to create the 9-tone complex:

$f_0 = 1400$ Hz; $f_1 = 1600$ Hz; $f_2 = 1800$ Hz; $f_3 = 2000$ Hz; $f_4 = 2200$ Hz;
$f_5 = 2400$ Hz; $f_6 = 2600$ Hz; $f_7 = 201$ Hz and $f_8 = 402$ Hz

you can hear a harmonic tone with a lower timbre than in [Sound E 7 0], however with a 1 Hz beat in the sound fragment:

[Sound E 7 1]

Experiment 3.7.2

To the 7-tone complex in Experiment 3.7.0 we have added the twin-tone contribution:

$f_7 = 199$ Hz; $f_8 = 398$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

you will hear an almost identical harmonic tone as in Experiment 3.7.1, again with a 1 Hz beat in the sound fragment:

[Sound E 7 2]

Experiment 3.7.3

We have now filled-in the frequencies:

$f_0 = 1430$ Hz; $f_1 = 1630$ Hz; $f_2 = 1830$ Hz; $f_3 = 2030$ Hz; $f_4 = 2230$ Hz;
$f_5 = 2430$ Hz and $f_6 = 2630$ Hz

you will be able to hear an enharmonic tone in the sound fragment:

[Sound E 7 3]

Remark

Listeners who are trained in music are able to distinguish the pitch and its shift upward, as reported by De Boer and others.
In our experience the sound is rather harsh.

Experiment 3.7.4

In his thesis [A I 1] De Boer has explained that the pitch of Experiment 3.7.3 can best be compared to the pitch of the harmonic tone complex for which we have filled in:

$f_0 = 1421$ Hz; $f_1 = 1624$ Hz; $f_2 = 1827$ Hz; $f_3 = 2030$ Hz; $f_4 = 2233$ Hz;
$f_5 = 2436$ Hz and $f_6 = 2639$ Hz

which has a 203 Hz fundamental frequency.

And with that frequency series you can hear a harmonic tone in the sound fragment:

[Sound E 7 4]

Remark

Here, according to previous results the pitch is equal to 203 Hz, the first harmonic of this series of 7 successive higher harmonics.

Experiment 3.7.5

To the 7-tone complex in Experiment 3.7.4 we have added the twin-tone contribution:

$f_7 = 203$ Hz; $f_8 = 406$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

to create the 9-tone complex:

$f_0 = 1421$ Hz; $f_1 = 1624$ Hz; $f_2 = 1827$ Hz; $f_3 = 2030$ Hz; $f_4 = 2233$ Hz;
$f_5 = 2436$ Hz; $f_6 = 2639$ Hz; $f_7 = 203$ Hz and $f_8 = 406$ Hz

you will hear a harmonic tone with a lower timbre than in Experiment 3.7.4, without a beat, in the sound fragment:

[Sound E 7 5]

Remark

Therefore, we made the attempt to search for this pitch in the enharmonic 7-tone complex of Experiment 3.7.3, by means of the pitch tracing mechanism. This mechanism consists of the addition of several different twin-tones to this tone complex, and to subsequently observe the changes in evoked beats.

In Experiment 3.7.6 we have started with the twin-tone of 203 Hz and 406 Hz because we can expect the pitch of 203 Hz De Boer has predicted.
*And if he is correct you will hear no beat with this twin-tone test***.**

Experiment 3.7.6

To the 7-tone complex in Experiment 3.7.3 we have added the twin-tone contribution:

$f_7 = 203$ Hz; $f_8 = 406$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

to create the 9-tone complex:

$f_0 = 1430$ Hz; $f_1 = 1630$ Hz; $f_2 = 1830$ Hz; $f_3 = 2030$ Hz; $f_4 = 2230$ Hz;
$f_5 = 2430$ Hz; $f_6 = 2630$ Hz.; $f_7 = 203$ Hz and $f_8 = 406$ Hz

you will hear an enharmonic tone with a lower timbre than in Experiment 3.7.3. However, instead of hearing an extra intensity to the pitch as expected, you will clearly hear a 3 Hz beat in the sound fragment:

[Sound E 7 6]

Experiment 3.7.7

We have replaced the added twin-tone in Experiment 3.7.6 by the twin-tone:

$f_7 = 202$ Hz and $f_8 = 404$ Hz

you will hear a beat of 2 Hz in the sound fragment:

[Sound E 7 7]

Experiment 3.7.8

We have replaced the formerly added twin-tone by:

$f_7 = 201$ Hz; $f_8 = 402$ Hz

you will hear a beat of 1 Hz in the sound fragment:

[Sound E 7 8]

Experiment 3.7.9

We have replaced the formerly added twin-tone by:

$f_7 = 200$ Hz; $f_8 = 400$ Hz

you hear that the beat completely disappears in the sound fragment:

[Sound E 7 9]

Experiment 3.7.10

We finally have replaced the formerly added twin-tone by:

$f_7 = 199$ Hz and $f_8 = 398$ Hz

you will hear that the beat returns to 1 Hz in the sound fragment:

[Sound E 7 r]

Remark

As no examiner can find any trace of a shift in pitch in these beat experiments, the only possible conclusion is that the pitch shift, which is observed and reported by trained listeners in music perception, actually is an illusion.

The actual pitch remains unchanged at 200 Hz, which is the smallest difference frequency in the enharmonic tone series.

3.8. Infrasound can also be heard according to the squaring principle

Experiment 3.8.0

When we fill in the twin-tone frequencies:

$f_0 = 600$ Hz; $f_1 = 610$ Hz

you presume you hear a tone of 605 Hz with a vibrato of 10 Hz in the sound fragment:

[Sound E 8 0]

Remark

This is commonly explained as the beat effect of the combination of the two near-by frequencies. However that is not how it works, as can be seen in the following series of experiments.

Experiment 3.8.1

We have filled in the triplet frequencies:

$f_0 = 600$ Hz; $f_1 = 610$ Hz and $f_2 = 620$ Hz

you will hear a tone of 610 Hz with a beat in the form of a vibrato of 10 Hz in the sound fragment:

[Sound E 8 1]

Experiments 3.8.2 – 3.8.3

By changing the f_1 in either 609 Hz or 611 Hz we have created the triplet:

$f_0 = 600$ Hz; $f_1 = 609$ Hz (or $f_1 = 611$ Hz) and $f_2 = 620$ Hz

you will hear a tone of 610 Hz with a 10 Hz vibrato, and an extra beat of 2 Hz in the sound fragment:

[Sound E 8 2] respectively [Sound E 8 3]

Experiments 3.8.4 – 3.8.5 – 3.8.6

We have added one of the following combinations to the triplet of Experiment 3.8.2 or 3.8.3:

$f_3 = 580$ Hz and $f_4 = 590$ Hz

or: $f_3 = 590$ Hz and $f_4 = 630$ Hz

or: $f_3 = 630$ Hz and $f_4 = 640$ Hz

you will hear that the extra 2 Hz beat is changed into a 1 Hz beat in the sound fragments:

[Sound E 8 4]; [Sound E 8 5] respectively [Sound E 8 6]

Remark

You have to consider that the only frequency that can be modulated is the 10 Hz pitch.

Experiment 3.8.7

To the triplet in Experiment 3.8.2 or 3.8.3 we have added another triplet:

$f_3 = 700$ Hz; $f_4 = 710$ Hz and $f_5 = 720$ Hz

you will hear that, apart from a change in timbre, the extra 2 Hz beat is changed into a 1 Hz beat in the sound fragment:

[Sound E 8 7]

Remark

The combination of the four difference frequency contributions of 9; 2 times 10 and 11 Hz results in a signal of 10 Hz with a beat of 1 Hz. Which is halved compared to the beat in Experiment 3.8.2 or 3.8.3.

Experiment 3.8.8

In the added triplet in Experiment 3.8.7 we changed the frequency $f_4 = 710$ Hz into $f_4 = 711$ Hz and thus this triplet became:

$f_3 = 700$ Hz; $f_4 = 711$ Hz and $f_5 = 720$

you will hear that the extra 1 Hz beat again changes into a 2 Hz beat in the sound fragment:

[Sound E 8 8]

Experiment 3.8.9

When we change the phase of the f_4 into 180° in Experiment 3.8.8 you will hear that the 10 Hz beat disappears almost completely. Instead of that you hear a not modulated 20 Hz vibrato in the sound fragment:

[Sound E 8 9]

Remark

This occurs because the two difference frequencies of 9 Hz and 11 Hz (evoked out of the 600 + 609 (or 611) + 620 Hz triplet) and the same two difference frequencies of 9 Hz and 11 Hz (evoked out of the 700 + 709 (or 711) + 720 Hz triplet) are – pair by pair – practically equal in amplitude and have an opposite phase. Therefore they cancel each other's contributions almost completely.

What remains is the combination of two contributions of the difference frequency of 20 Hz as a result from the combinations 620 – 600 and 720 – 700 Hz, heard as a 20 Hz vibrato.

References

A II 1. De Boer E. (1956) On the "residue" in hearing. Thesis; University of Amsterdam.