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Perception of Emotion Induced by Musical Sounds and Expressions

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Department of Civil and Environmental Engineering
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Degree of Master of Science

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Professor Mendel Kleiner

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Abstract

When we are subjected to different kinds of sounds, we consciously or subconsciously react to these. There are many different parameters of the sounds that determine the reaction, e.g. performance related parameters such as rhythm, tempo, timbre, attack, etc. and harmonic parameters meaning musical harmonies. Some of these parameters will more or less influence activation and some more or less influence valence.

To comprehend how people react to musical sounds and acoustic parameters, several sounds and parameters (e.g. staccato, ritardando and vibrato) have been taken from music theory and have been tested on their own. In this thesis the perception of emotion of these sounds have been rated by asking people how they thought the sound sounded. –Did it sound happy/sad and/or stressing or calming?

Results show that most of the acoustical parameters tested affect human perception. An increase in sound level for example, increases the perceived activation. This means that the sound is perceived as more stressing or arousing as the sound level increases. Sound level had however no influence on how happy or sad the sound was perceived. A change in pitch showed influence on both valence and activation. A high pitch sound was perceived as both more activating and happier than a low pitch sound.

Keywords: Emotion, utilization cue, acoustic parameter, musical harmony, harmonic interval, psycho acoustics, music psychology, perception of emotion

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Last but not least I would like to thank Börje Wijk for always supplying his expertise and assistance in material and equipment matters.

Thank you all!

The whole problem can be stated quite simply by asking, 'Is there a meaning to music?' My answer would be, 'Yes.' And 'Can you state in so many words what the meaning is?' My answer to that would be, 'No.'

Aaron Copland
US composer (1900 - 1990)

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1 Introduction

It is commonly agreed that music affects us emotionally. But can these emotions be controlled by simple parameters or attributes separately if you extract them from within the music? Is it possible to withdraw the specific information from a music piece that makes the piece happy, sad, stressing, calming, etc.? This master thesis aims to deal with the human response to musical expressions and musical sounds such as harmonic intervals. I will deal with the possibility of determining how a person will respond or react when presented with a sound. This knowledge could be very useful when designing sounds in general.

In “music and emotion”, [1], Juslin describes several utilization cues that are used to express five different discrete emotions (tenderness, anger, sadness, happiness and fear) in music when performed by musicians. Such utilization cues can be e.g. staccato, sound level variability and/or mean tempo. The expression ‘Utilization cue’, however, is not quite accurate for this thesis. ‘Utilization cue’ is more accurately used in a so called lens-model where one models what cues a perceiver use to decode an expression. (For a further description of the lens-model and its use, see for example Juslin (2000), [9]). What are used in this thesis are acoustic parameters underlying emotional expression in music. Even though this thesis is based on Juslin’s research on musical psychology, the term ‘Acoustic parameter’ will be used to not mix up the concepts.

The main hypothesis of this thesis says that these acoustical parameters can be extracted from its context and that they then can be used as separate acoustic parameters to affect human perception and reaction to a sound (see chapter 2.1). First, tests on some of the acoustic parameters compiled from figure 2.1 in table 2.1 will be performed (see chapter 2.1). Secondly, tests on harmonic intervals will be performed (see chapter 2.2). The harmonic intervals will both be tested for sinusoidal intervals and intervals played by an instrument. The chosen “instrument” is a sampled string ensemble.

1.1 Method

The sounds that were designed and created for this thesis were tested in two stages, where both stages contained both the acoustic parameters and the harmonic intervals. The first stage was to get a general idea of how the sounds affect a subjected person and the second stage was to actually measure how the subjected person reacted. This was done by, in the first stage asking the subjected persons how they thought the sound sounded (see chapter 5), and in the second stage measuring the physiological response to the sounds with facial EMG and GSR equipment (see chapter 7)

1.2 Background

This master thesis is a realization of an idea the Chalmers Room Acoustic Group (CRAG) at the Division of Applied Acoustics, Chalmers University of Technology, have had. The application is made on a project that the CRAG team has been assigned by Volvo Trucks. The Assignment was to develop better information and warning signals in the truck compartment. This thesis is focused on the sound design part where I will investigate the possibility of using musical sounds and acoustic parameters.

2 Background Theory

To be able to start this thesis and to understand what to test and what to assume, there are a few basic concepts that need to be examined and explained, concerning basic musical theory.

As have been mentioned before, the application of this thesis is in sound design. The possibility of knowing how a person will react or respond to a sound before the sound even has been played would be very useful to a sound designer. One could use the acoustic parameters as building blocks and 'guide' the emotion on the valence-activation chart to create the desired sound.

2.1 Utilization cues

In this thesis the figure 14.2 in [1] (Figure 2.1, below), is central. Empirical tests have shown that musicians can express emotions in a piece of music to a public by using so called, utilization cues. This figure shows that discrete emotions (Tenderness, happiness, etc.) can be described by two factors, activation and valence. For example, tenderness is a combination of very positive valence and very low activation, while sadness is a combination of very low activation and very little negative valence. Valence describes how positive and/or negative a sound sounds and activation describes how calm and/or arousing a sound sounds. In figure 2.1 below one can see what utilization cues that were used to express each emotion.

Hypothetically it would be possible to compile and extract these utilization cues to acoustic parameters to see the effect each cue has on the activity axis, the valence axis or both. This is the aim of the thesis, to try to separate the acoustic parameters and see if a pure correlation of each can be found on the activation-valence chart.

After the compilation the conclusion was drawn that a single cue utility mostly affects one of the two axes, the valence or the activity. The compilation showed that activation was most commonly affected. Only five of the acoustic parameters could directly be translated to the valence axis, of which three of them showed to be affecting both axes. However, only activation or valence affect is not the expectation, but that all parameters will in fact have influence on both activity and valence though one of the two axes might be dominantly affected. Table 2.1 shows the compilation made in this thesis.

Three different pitches will also be tested to see how pitch influences the perception of the sounds. The three pitches are called: Pitch 5, Pitch 6 and Pitch 7. The reason is simply because it refers to the order from the first audible C (≈16.4 Hz), i.e. C = 16.4 Hz would be the C in Pitch 1 and C = 262.4 Hz would be the C in Pitch 5.

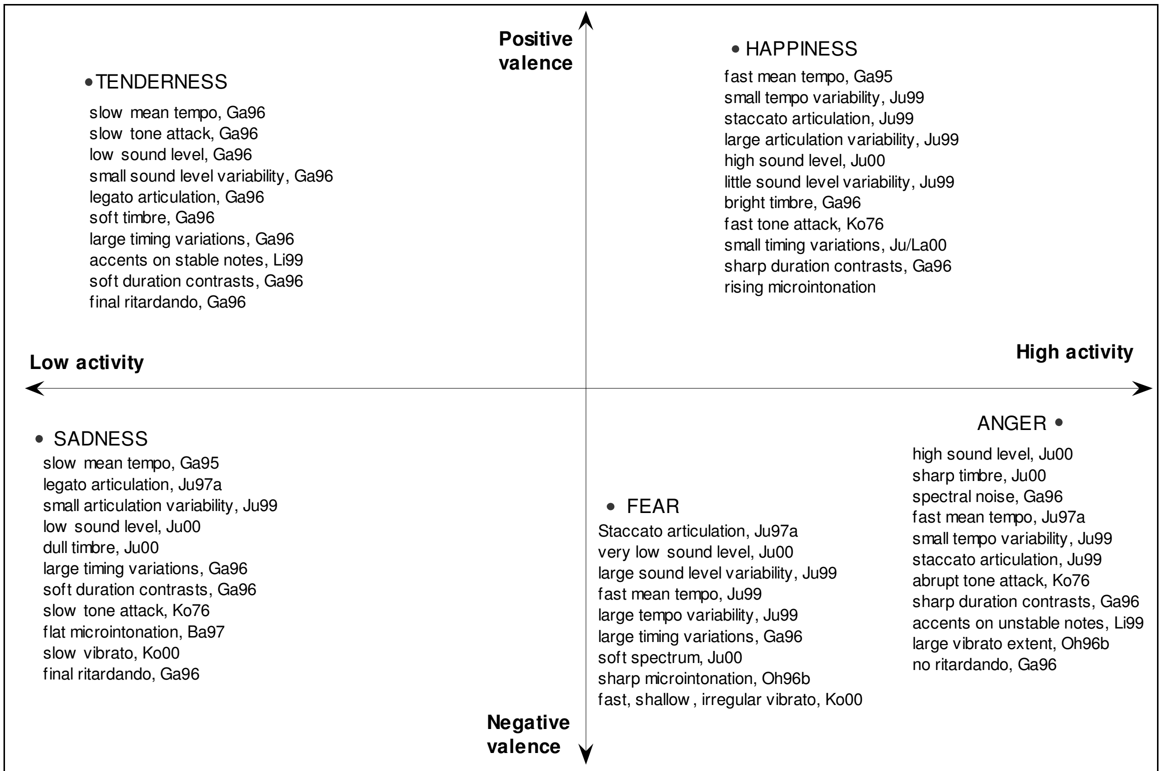

Figure 2.1: Cue utilization in performers' communication of emotion in music[1].

Table 2.1: Compilation of figure 2.1. The cue's effect on valence and activation

Cue	Valence affective		Activity affective	
	Positive	Negative	High	Low
Microintonation	Rising		Rising	Flat
Sound level variability	Small	Large		
Timbre	Bright/Soft		Bright/Sharp	Dull/Soft
Timing variations		Large		
Articulation variability	Large	Small	Large	Small
Accents			on unstable notes	on stable notes
Articulation			Staccato	Legato
Mean tempo			Fast	Slow
Ritardando			None	Final
Sound level			High	Low
Timing variations			Small	Large
Tone attack			Fast/Abrupt	slow
Vibrato			Fast/Shallow/ Irregular/large	Slow
Spectrum			Spectral noise	Soft
Duration contrasts			Sharp	Soft

[1] A copy of figure 14.2 in [1].

Other than these acoustic parameters we are hypothetically also most affected by other expressions in music, for example the harmonies. Basically every piece of music includes harmonies that bring a certain character or expression to the sound. To test the perception and response of these, an insight in the properties of these is necessary.

2.2 Harmonic Sounds and the Chromatic Scale

In western music we traditionally use the chromatic scale, which is a scale consisting of twelve semitone steps from the fundamental tone to its octave. The tone steps are calculated using equation 1 below.

Equation 1: Formula for the frequencies of the semitones in a chromatic scale.

$$f_n = f_{fundamental} \cdot 2^{n/12}$$

f_n = frequency of the nth semitone
$f_{fundamental}$ = frequency of the fundamental tone

Each step is named and is probably very familiar to most people:

Table 2.2: The twelve semitone steps of the chromatic scale.

Name	Fundamental	Cromatic 2nd	Major 2nd	Minor 3rd	Major 3rd	Perfect 4th	Diminished 5th	Perfect 5th	Minor 6th	Major 6th	Minor 7th	Major 7th	Octave
Semitone	1	2	3	4	5	6	7	8	9	10	11	12	13
Note	C	C# or Db	D	D# or Eb	E	F	F# or Gb	G	G# or Ab	A	A# or Bb	B	C
# = sharp b = flat													

There are many different chords and intervals that can be studied. This investigation will however only include the 13 intervals that you can have with a C as a fundamental tone (including the unison interval). The C is chosen for no other reason than that the C is the first tone in the chromatic scale.

Table 2.3: Intervals used in test, showing fundamental and harmonic frequencies.

Intervals:		Pitch [Hz]:					
		Pitch 5		Pitch 6		Pitch 7	
		Fund.	Harm.	Fund.	Harm.	Fund.	Harm.
Unison	C	262.6	**262.6**	524.2	**524.2**	1048	**1048**
Chromatic **semitone**	C-Db	262.6	**278.2**	524.2	**555.4**	1048	**1110**
Major **2nd**	C-D	262.6	**294.6**	524.2	**588.4**	1048	**1176**
Minor **3rd**	C-Eb	262.6	**312.2**	524.2	**623.2**	1048	**1246**
Major **3rd**	C-E	262.6	**330.6**	524.2	**660.1**	1048	**1319**
Perfect **4th**	C-F	262.6	**350.2**	524.2	**699.3**	1048	**1398**
Diminished **5th**	C-Gb	262.6	**371.0**	524.2	**740.9**	1048	**1481**
Perfect **5th**	C-G	262.6	**393.0**	524.2	**784.9**	1048	**1569**
Minor **6th**	C-Ab	262.6	**416.4**	524.2	**831.5**	1048	**1662**
Major **6th**	C-A	262.6	**441.0**	524.2	**880.9**	1048	**1761**
Minor **7th**	C-Bb	262.6	**467.2**	524.2	**933.3**	1048	**1865**
Major **7th**	C-B	262.6	**494.8**	524.2	**988.7**	1048	**1976**
Octave	C-C	262.6	**524.2**	524.2	**1048**	1048	**2094**

The reason for trying intervals and not a few chords is that all chords are built up by a combination of intervals. For example, a major triad chord is a combination of a major third and a fifth, whereas a minor triad chord is a combination of a minor third and a fifth. Furthermore, aiming to try chords out would result in a very large number of sounds, and the analysis of them would be very difficult due to their complexity.

2.2.1 Musical Consonance and Dissonance

Something must also be said about consonance and dissonance in harmonics. There are three types of intervals [3]: the perfect consonance intervals, the imperfect consonance intervals and the dissonant intervals. Indifferently they all contain the fundamental tone, but they also contain an overtone creating an interval (apart from the unison tone which is considered a perfect consonance “interval”).

Perfect Consonance

Consonance appears when the frequencies of the interval are further apart than their respective critical bands. The perfect consonance intervals are four. They are (1) the unison tone, (2) the octave, (3) the perfect fourth, and (4) the perfect fifth.

Imperfect Consonance

The second type of interval is the imperfect consonance intervals, and they are the (5) minor third, (6) major third, (7) minor sixth and (8) the major sixth. The imperfect consonance intervals have frequencies that lie close to their critical bands.

Dissonance

For any interval produced by an instrument, the dissonant intervals include the (9) chromatic semitone, (10) major second (11) major seventh, (12) minor seventh and (13) diminished fifth. It is however important to keep in mind that even these dissonant intervals create sounds that people often can think of as pleasant.

Table 2.4: Each interval[2], its ratio and the critical bandwidths.

fL = Lower frequency limit fc = Center frequency fu = Upper frequency limit		Fundamental tone			Interval overtone			Nearest harmonic of fundamental			
		fL	fc	fu	fL	fc	fu	fL	fc	fu	
Unison	1/1	466	523	580	466	**523**	580	965	1046	1127	**U**
Chr. **semitone**	36/35				496	**554**	612				**D**
Major **2nd**	9/8				528	**587**	647				**D**
Minor **3rd**	6/5				562	**622**	683				**D**
Major **3rd**	5/4				597	**659**	721				**C**
Perfect **4th**	4/3				635	**698**	762				**C**
Diminished **5th**	10/7				674	**740**	806				**C**
Perfect **5th**	3/2				716	**784**	852				**C**
Minor **6th**	32/21				761	**831**	900				**C**
Major **6th**	8/5				808	**880**	952				**C**
Minor **7th**	9/5				857	**932**	1007				**D**
Major **7th**	15/8				910	**988**	1066				**D**
Octave	2/1				965	**1047**	1128				**U**
Acoustically consonant (C), dissonant (D) or unison (U).											

The critical bandwidths from table 2.4, above tells us that a sinusoidal harmonic interval, i.e. a sound with exclusively the fundamental tone and the harmonic interval overtone, would be consonant for all intervals from major 3rd and above. However, the second nearest overtone will be dissonant for more intervals, and so on.

[2] There are more intervals depending on if you talk about an augmented or a diminished tone or if you talk about a chromatic or a diatonic scale, etc. However, for example, a diminished sixth will be treated in the same way as an augmented fifth. Furthermore the chromatic twelve tone scale will be used.

3 Hypothesis

It is a common fact that music affects us emotionally. The music we listen to makes us happy, sad, angry, calm etc. When musicians play music they use different acoustic parameters to express what they want to mediate. This thesis aims to deal with the acoustic determinants of emotional perception and reaction in non-musical and non-vocal stimuli.

The hypothesis says that the acoustic parameters used in music are also influential on emotional perception and reaction when used in simpler acoustic context such as tones or chords. A main aim is to map the selected acoustic parameters to valence and activation ratings. Hypothetically there is a relationship between the acoustic parameters and how each is used. To be able to detect the activity or valence arousal from the acoustic parameter the parameters need to be varied from small to high usage, e.g., varying a slow mean tempo to a high mean tempo. Five degrees for each acoustic parameter is to be tested, to see the effect of each, and hopefully discover relationships between the parameters. Moreover, to eliminate all influence of unknown parameters the sounds must be designed in a very controlled way and also, in a way that influences from other parameters easily can be detected and considered.

Not all of the acoustic parameters can be tested in this thesis. The parameters have been chosen for the reason of being hypothetically more effective, and because of their possibility of being parameterized. The chosen acoustic parameters are seen in table 3.1.

Table 3.1: Choice of acoustic parameters for the tests.

	Hypothetically effective on:	
Utilization Cue	Activation	Valence
Pitch	X	X
Background Noise	X	
Ritardando	X	
Sound Level	X	
Sound Level Variability		X
Articulation	X	
Mean Tempo	X	
Tempo Variability	X	X
Tone Attack	X	
Vibrato	X	

3.1 Selected Acoustic Parameters

In this chapter the hypothetically expected perception of the acoustic parameters is stated. The acoustic parameters will furthermore be described as how they will be designed for the listening test.

3.1.1 Pitch

It is assumed, that the pitch in which the music or sound is reproduced will make a considerable difference on the perception of both valence and activation. Only consider a piece of music played in a certain pitch. If it was played in a low pitch, would not we think of it as a bit sadder or maybe even “darker”? On the other hand, if it was to be played in a high pitch, would not we think of it as happier and lighter? One could also consider a low pitch sound calmer than a high pitch sound. Hence, pitch as an acoustic parameter is hypothetically both activation and valence effective.

Furthermore, the acoustic parameters, and also the intervals, may be differently perceived themselves when played in a certain pitch. Each acoustic parameter will therefore be tested in three different pitches to simultaneously record the influence of pitch. The fundamental tone of the three pitches is a musical C in three following octaves, C_5 = 262.6 Hz, C_6 = 524.2 Hz and C_7 = 1048 Hz. (Approximately true for a piano tuned to A = 441 Hz). This will hypothetically give a general idea of how a pitch shift is perceived.

3.1.2 Background Noise

According to the hypothesis in table 2.1 (after compiling figure 14.2 in [1]) a sound containing spectral noise affects the subjected person to high activation, whereas a soft spectrum contributes to a low activation. The SNR (Signal to Noise Ratio) of the five degrees of background noise in the test will be:

Equation 2: Signal to Noise Ratio

$$SNR = \left(\frac{A_{Signal}}{A_{Noise}}\right)^2 = \left[\begin{array}{c} A_{Signal} = 1 \\ A_{Noise} = \begin{cases} 0.1 \\ 0.2 \\ 0.3 \\ 0.4 \\ 0.5 \end{cases} \end{array}\right] = \begin{cases} 100 \\ 25 \\ 11.1 \\ 6.25 \\ 4 \end{cases} = \begin{cases} 20\ \text{dB} \\ 14\ \text{dB} \\ 10.5\ \text{dB} \\ 8\ \text{dB} \\ 6\ \text{dB} \end{cases} \quad \text{A is the amplitude of the signals.}$$

3.1.3 Ritardando

The presence of a final ritardando hypothetically leads to a low activation, and no ritardando analogically brings a higher activation. The five ritardando sounds in the test will have different lengths in seconds but still have the same total number of tones. Furthermore, the final five tones will have longer and longer duration. Hence, an exceeding ritardando is introduced. The final five tones of each ritardando have the lengths shown below.

Ritardando 1: 100 – 150 – 200 – 250 – 300	[ms]
Ritardando 2: 150 – 250 – 350 – 450 – 550	[ms]
Ritardando 3: 200 – 350 – 500 – 650 – 800	[ms]
Ritardando 4: 250 – 450 – 650 – 850 – 1050	[ms]
Ritardando 5: 300 – 550 – 800 – 1050 – 1300	[ms]

As shown in figure 3, the lengths of the breaks are equally long for all signals (100 ms). The first tones have the length of 50 ms.

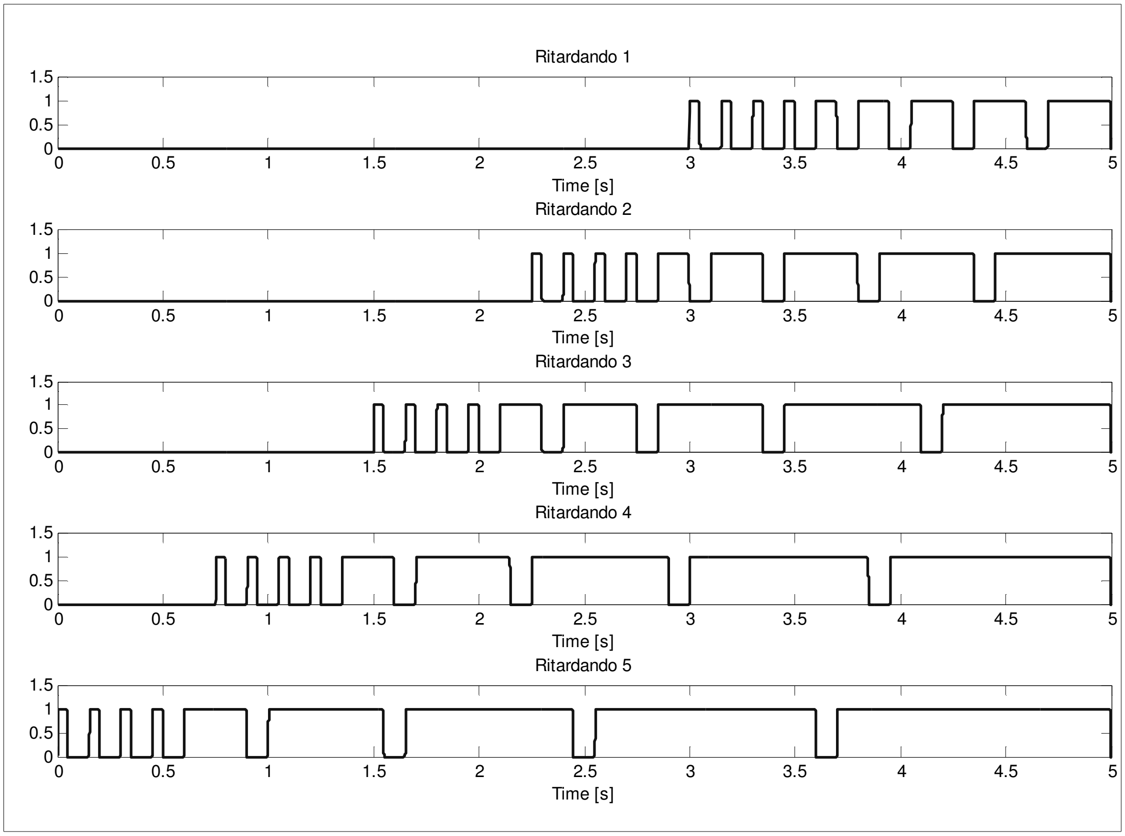

Figure 3.1: The tone length of the ritardando filters 1 through 5.

3.1.4 Sound Level

The hypothesis also says that depending on the sound level, a subjected person will be more or less activated when subjected to a high respectively low sound level. To test this, five different sound levels will be played to the test persons. The sound levels are shown below.

Sound Level 5 = ± 0 dB, re Sound Level 5
Sound Level 4 = – 5 dB, re Sound Level 5
Sound Level 3 = – 10 dB, re Sound Level 5
Sound Level 2 = – 15 dB, re Sound Level 5
Sound Level 1 = – 20 dB, re Sound Level 5

As seen above, Sound Level 5 is the strongest sound and Sound Level 1 the weakest.

3.1.5 Sound Level Variability (SLV)

Varying the sound level will affect valence according to the hypothesis. The hypothesis says that a small SLV will be perceived as positive and a large SLV will be perceived as negative on the valence axis. The test SLV varies with a sinusoidal period length of 1.25 s. The highest and lowest relative sound level can be read from figure 3.2.

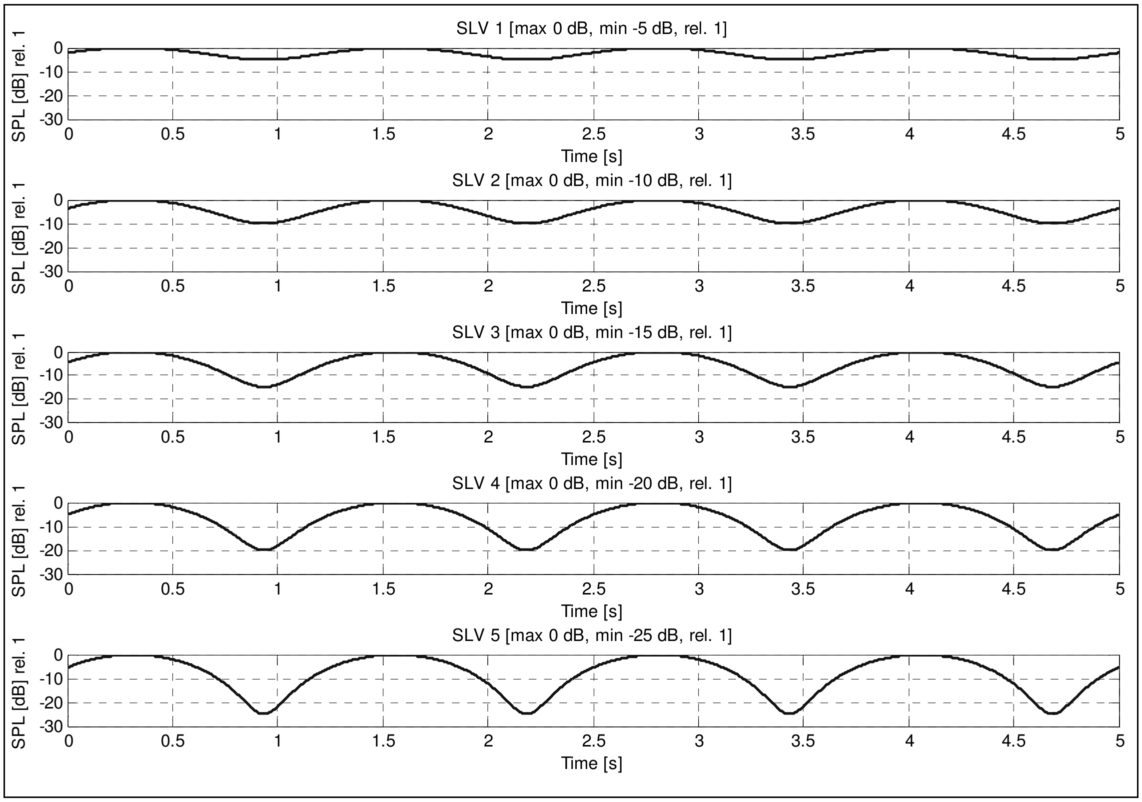

Figure 3.2: Sound Level Variability of the five test sounds.

3.1.6 Articulation

The acoustic parameter 'Articulation' can vary from staccato to legato. A staccato articulation will, according to my hypothesis, be high activity effective and legato, thus, low activity effective. The tempi of all five sounds are the same (120 bpm), but the tone lengths increase as the sound goes from staccato to legato, as shown in figure 3.3 and figure 3.4.

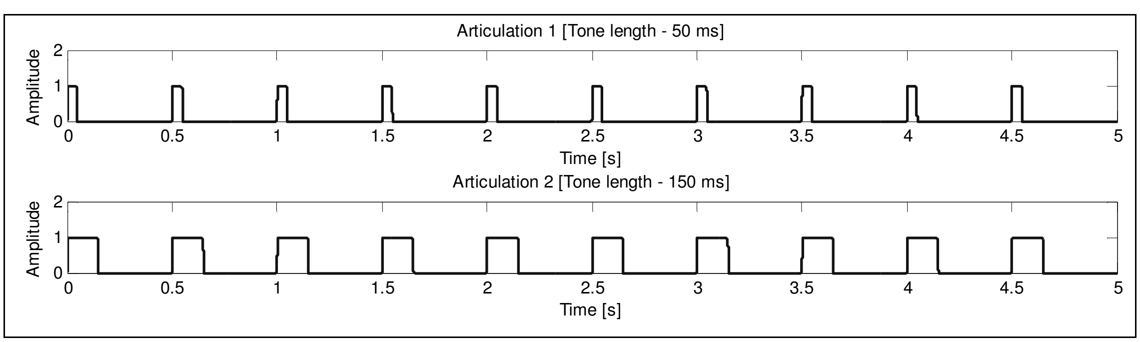

Figure 3.3: Tone length the articulation sounds 1 through 2.

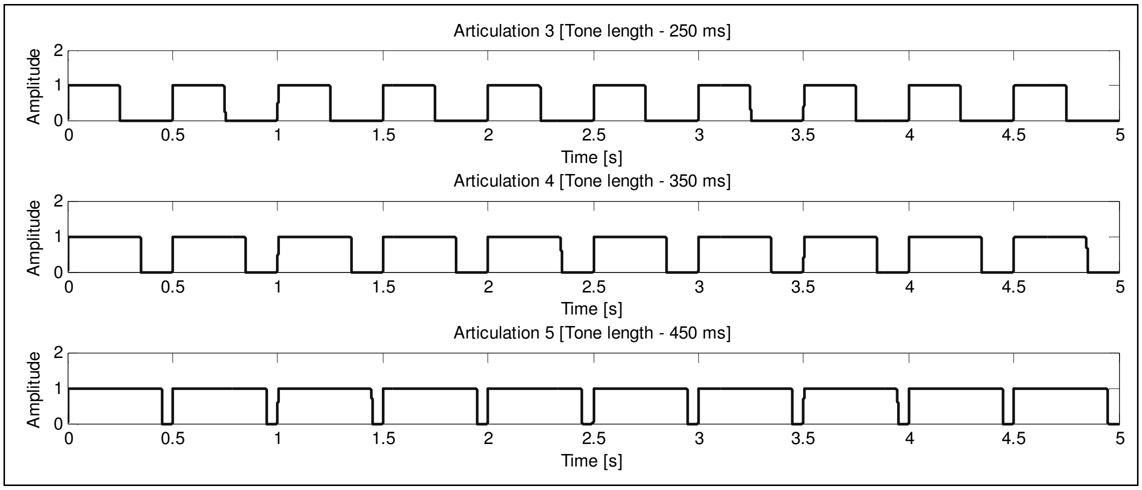

Figure 3.4: Tone length the articulation sounds 3 through 5.

3.1.7 Mean Tempo

With a fast and slow mean tempo, activation should be perceived as high respectively low. The mean tempi have an increasing tempo of 60 bpm (beats per minute) between the levels. Each level's tempo can be read in figure 3.5. What also is shown in figure 3.5 is that the ratio between tone length and break length is 1:1.

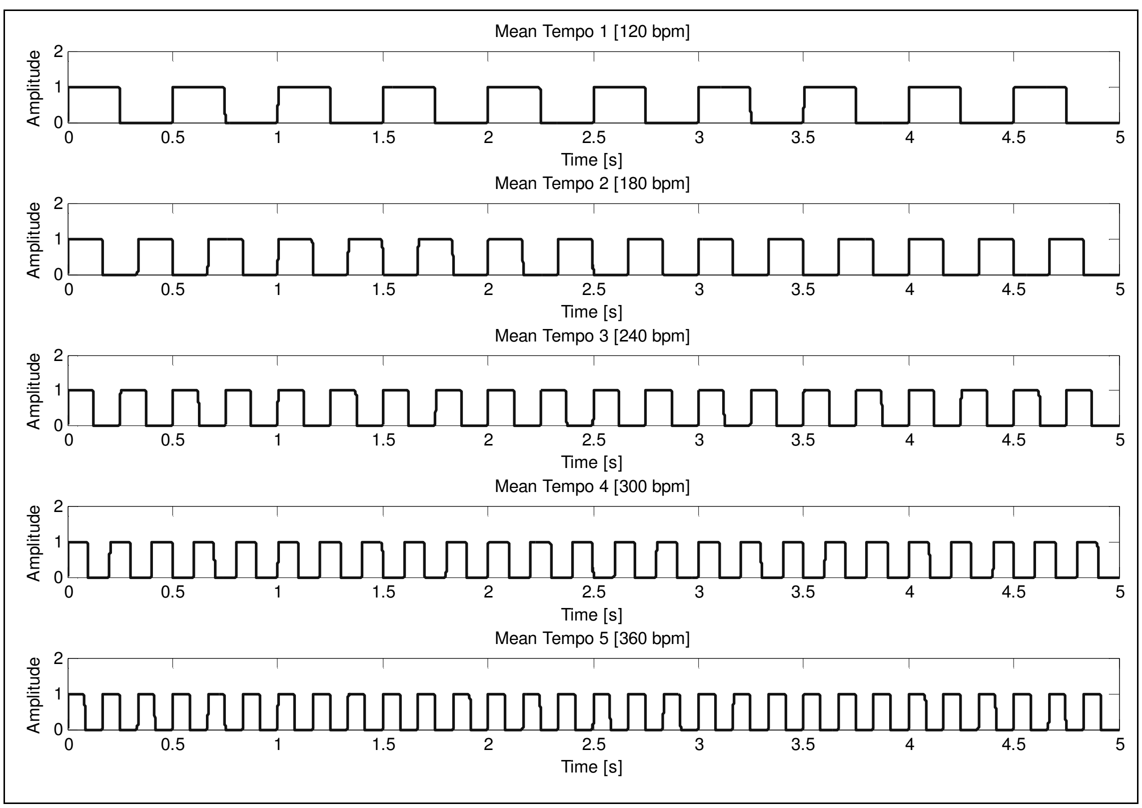

Figure 3.5: Mean tempo of the test sounds.

3.1.8 Tempo Variability

This is an acoustic parameter that has not directly been reviewed before. However, in [1] one can read about duration contrasts and timing variations. These might be considered in the same way but according to my compilation of figure 14.2 in [1], duration contrasts is an activation variable, and timing variation would in a large extent affect valence negatively.

The hypothesis says that tempo variability will be effective on both activation and valence in a larger extent than most of the other acoustic parameters, so that 'emotions can be moved diagonally' on the activation-valence figure.

Important is, that when designing the *Tempo Variability* sounds, one should stay away from common beats. Such would be half beats and triplets, etc. The reason for not using common beats is that musically trained people might start to hear the beat's sub divisions.

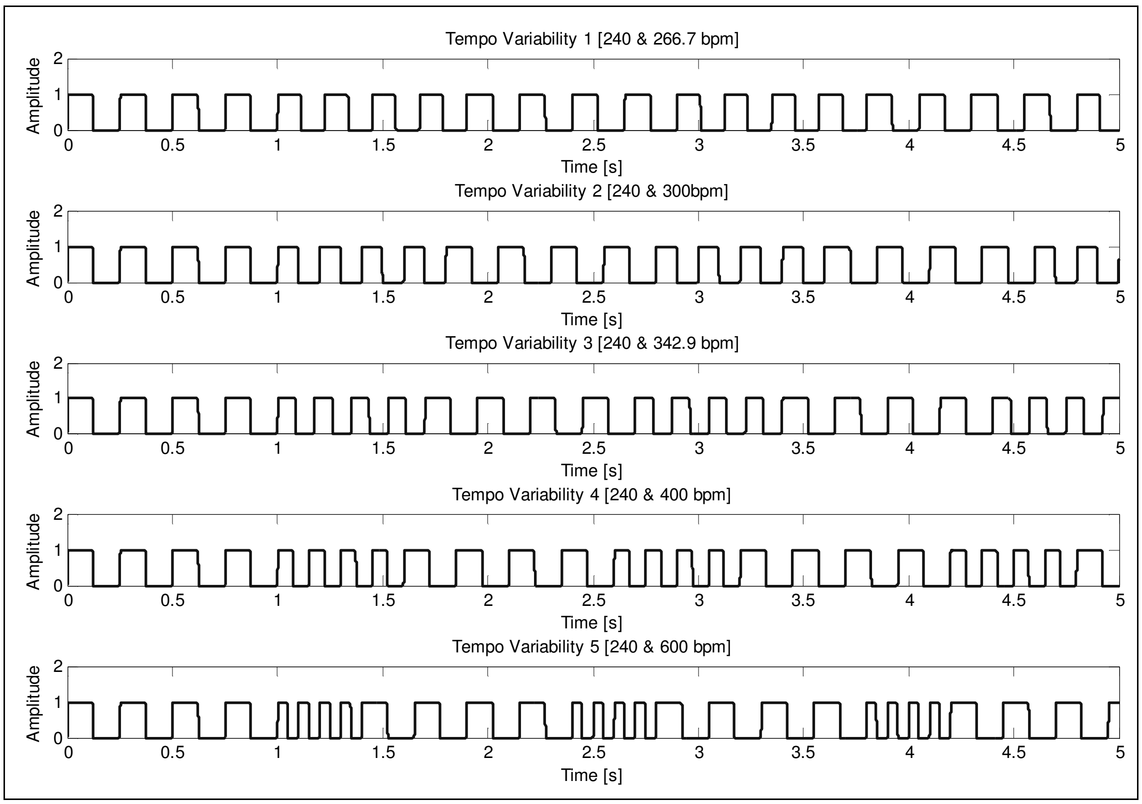

Figure 3.6: Tempo variability of the five test sounds.

All five sounds have a fundamental beat of 240 bpm, in which three sets of another tempo is added (see figure 3.6).

3.1.9 Tone Attack

Tone attack is also believed to be mostly activation effective. A fast or abrupt tone attack will lead to high activation and low activation will be asserted by a slow tone attack.

The five tone attacks used in the test is shown in figure 3.7. They all have the same tempo and sound level.

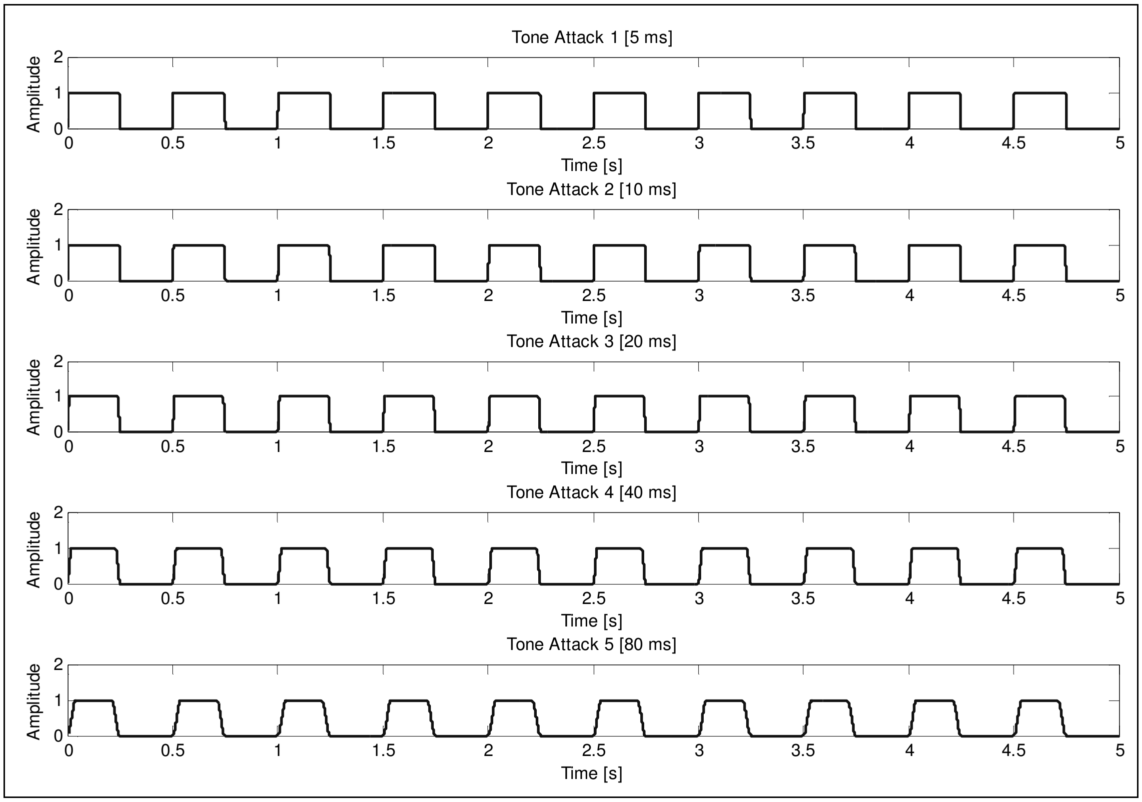

Figure 3.7: Tone attack of the five sounds.

3.1.10 Vibrato

The vibrato cue contains at least two factors that decide how it will be perceived, namely the vibrato amplitude and vibrato frequency (explained in figure 3.8). However, both are hypothetically more activation effective. The tested vibratos are:

Vibrato 1: $C_{5,6,7}$ – Vibrato frequency = 2 Hz – Vibrato amplitude = 0.06
Vibrato 2: $C_{5,6,7}$ – Vibrato frequency = 8 Hz – Vibrato amplitude = 0.06
Vibrato 3: $C_{5,6,7}$ – Vibrato frequency = 5 Hz – Vibrato amplitude = 0.12
Vibrato 4: $C_{5,6,7}$ – Vibrato frequency = 2 Hz – Vibrato amplitude = 0.18
Vibrato 5: $C_{5,6,7}$ – Vibrato frequency = 8 Hz – Vibrato amplitude = 0.18

Tones C_5, C_6 and C_7 have amplitudes 1.

Vibrato frequency and amplitude can easily be explained with the use of an analogy of a stringed instrument such as a violin or a guitar. If one was to hold down a string and pull and push my finger along the string, the vibrato frequency would be equivalent to how fast my finger oscillation was and the vibrato amplitude to how far the string was pulled and pushed (Figure 3.8).

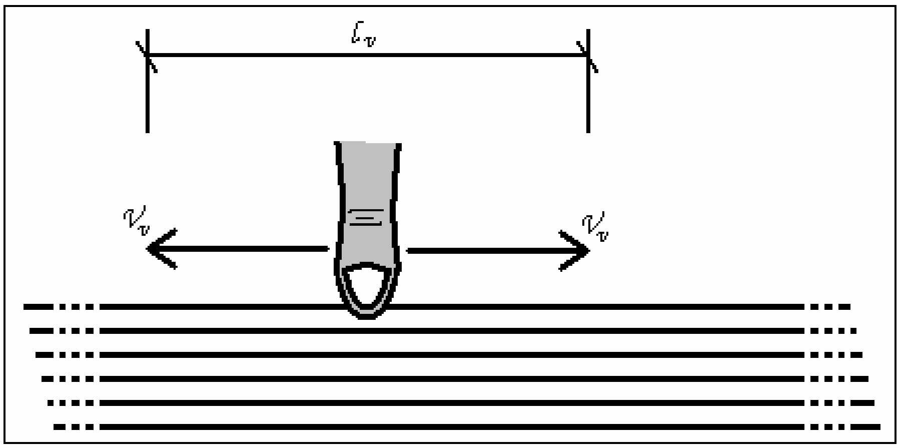

Figure 3.8: Description of vibrato frequency and amplitude.

Vibrato frequency can be described as oscillation velocity over the length the string is pulled/pushed. Vibration amplitude can be described as the length the string is pulled in both directions. Mathematically this frequency modulation can be calculated by equation 1, below.

Equation 3: Vibrato formula.

$$C_{Vibrato} = \sin(2 \cdot \pi \cdot (f_{fundamental} + A_{Vibrato} \cdot \sin(2 \cdot \pi \cdot f_{vibrato} \cdot t)) \cdot t)$$

$C_{Vibrato}$: Signal of the vibrating tone

$f_{fundamental}$: Fundamental frequency of the sound (the mean frequency) in Hertz

$A_{Vibrato}$: Amplitude of the vibrato in $\%/_{100}$ of the vibrating tone's amplitude

$f_{Vibrato}$: Frequency of the vibrato in Hertz

t : Time length of the sound in seconds

3.2 Selected Musical Sounds

Humans tend to appreciate consonance and dislike dissonance in sounds. Consonance between two or more frequencies appears when the frequency ratio between the sounds is a simple fraction, such as 2/1 (octave), 3/2 (perfect fifth), etc. Dissonance is perceived for not so simple fractions such as 53/50, 41/42, etc. [2]. This coincides with the fact that in the case with more simple fractions, the critical bands of the interval tones are kept apart. The most common opinion is that minor and major keys are perceived as ‘sad’ respectively ‘happy’.

In this way consonance and dissonance in sounds might be very useful when “guiding” a person’s emotional reaction. Valence could be affected by for example minor and major triad with different coloration, and the activity rate could be affected by including dissonance in the chords. However, sinusoidal intervals which contain no natural overtones will be less likely to be dissonant, only the first couple of tone steps will be.

3.2.1 Intervals

The good thing about using sinusoidal sounds is that you will get no unwanted influence of natural overtones (see figure 3.9). Firstly, the affects of only the intervals are wanted. Furthermore, it is interesting to be able to compare these results to intervals produced by a musical instrument, in this case, sampled strings.

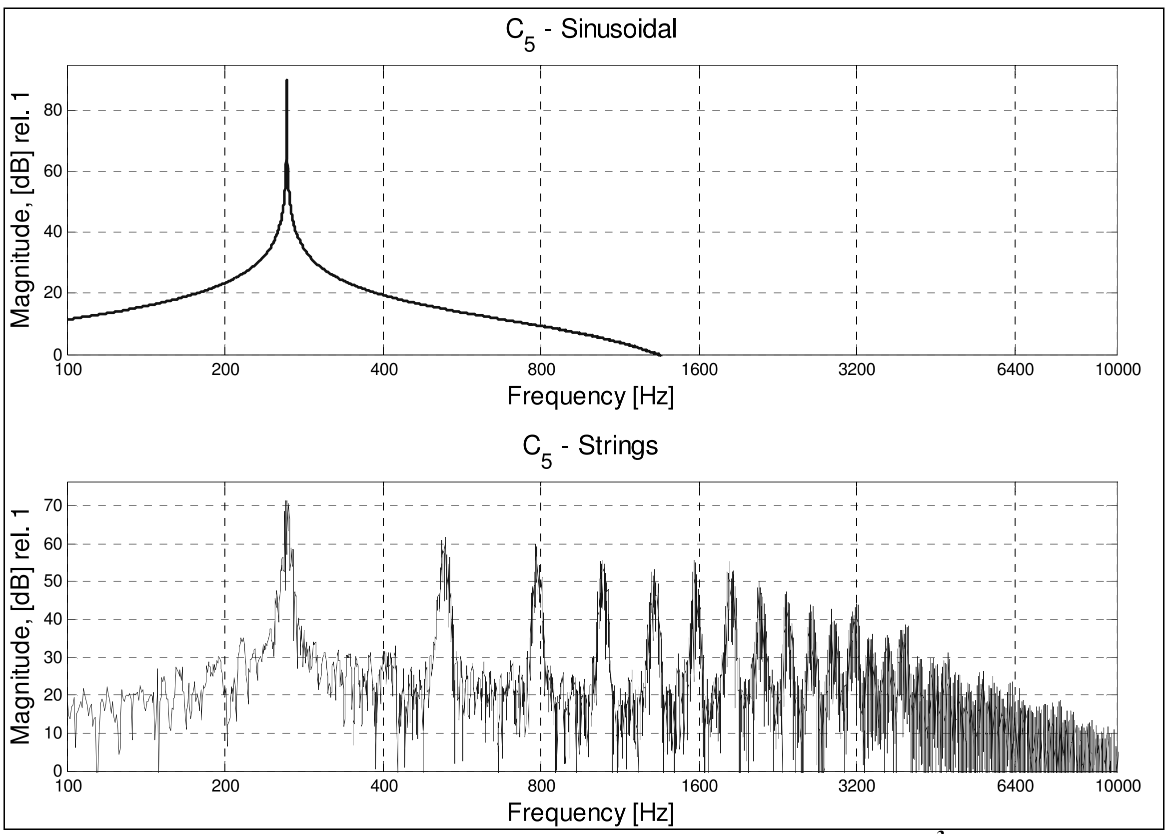

Figure 3.9: Frequency components of the sinusoidal tone and string sounds for C_5.[3]

[3] The plot over the frequency component of the sinusoidal tone shows windowing effects.

Judging from figure 3.9, one might think that the sinusoidal sound sounds stronger. However, a calculation of the overall A-weighted sound pressure level (SPL) shows that the sounds are equally strong (Equation 4).

Equation 4: Calculation of overall A-weighted SPL.

$$p^2_{\sin,overall} = \sum_{f=1}^{10kHz} \left(10^{A_W(f)/10} + p^2_{\sin}(f) \right) \Rightarrow SPL^{Sin}_{overall} = 10\log\left(\frac{p^2_{\sin,overall}}{1} \right) = 149.9\ dBA\ re\ 1$$

$$p^2_{str,overall} = \sum_{f=1}^{10kHz} \left(10^{A_W(f)/10} + p^2_{str}(f) \right) \Rightarrow SPL^{str}_{overall} = 10\log\left(\frac{p^2_{str,overall}}{1} \right) = 149.9\ dBA\ re\ 1$$

f : frequency

$p_{\sin}$: pressure of the sinusoidal sound at each frequency.

p_{str} : pressure of the string sound at each frequency.

$p^2_{overall}$: Summation of the squared pressures of each frequency.

A_W : A - weighting value at each frequency

It should be noted that the SPL produced by the headphones was not 149.9 dB, but this SPL is a relative level to a sound in MATLAB [10] normalized to 1. All sounds where normalized to 1 in MATLAB.

If a sound produced by an instrument was played, the sound would contain all the natural overtones included by the particular instrument. All instruments have their own set of characteristic overtones. Therefore, both sinusoidal harmonic intervals and intervals produced by an instrument will be tested. For this thesis the choice of instrument is a sampled string quartet. The sampled sound is used because the human factors on how they play it, such as accents and other parameters, needs to be eliminated in this test.

The same harmonic intervals that are described in chapter 2.2 (Table 2.3) will be used for both the sinusoidal and the string sounds.

It would in both the sinusoidal and string cases be expected that the more dissonant intervals give a higher activation, and probably more negative valence. The perfect and imperfect consonance intervals should be less activation effective and have more influence on valence. The assumption could be made, from what people generally believe that a major timbre and a minor timbre should be positive respectively negative valence effective. This is however something that not can be accepted straight away. To some extent it is believed to be true, but not for all major respectively minor intervals. It is assumed that the largest influence on valence will be the influence of the minor and major thirds, which are the distinction between a minor and a major chord.

3.2.2 Microintonation, Consonance and Dissonance

One semitone step corresponds to an increase in frequency by 5.9-6.0 %, and analogously 12.2 % for a whole tone step. The same sounds as in table 2.3 will be used (except for the unison tone), but the harmonic overtone will be pitch modulated in the sounds to make them (more) dissonant. Microintonation will only be tested on the sinusoidal harmonic intervals. Therefore the only overtone is the higher pitched tone of the interval. Figure 3.10 shows how the interval overtone is pitch modulated in percentages over time.

Sound 1 – Rising microintonation
A linear increase in pitch by 3% of the overtone in the interval (Figure 3.10)

Sound 2 – Falling microintonation
A linear decrease in pitch by 3% of the overtone in the interval (Figure 3.10)

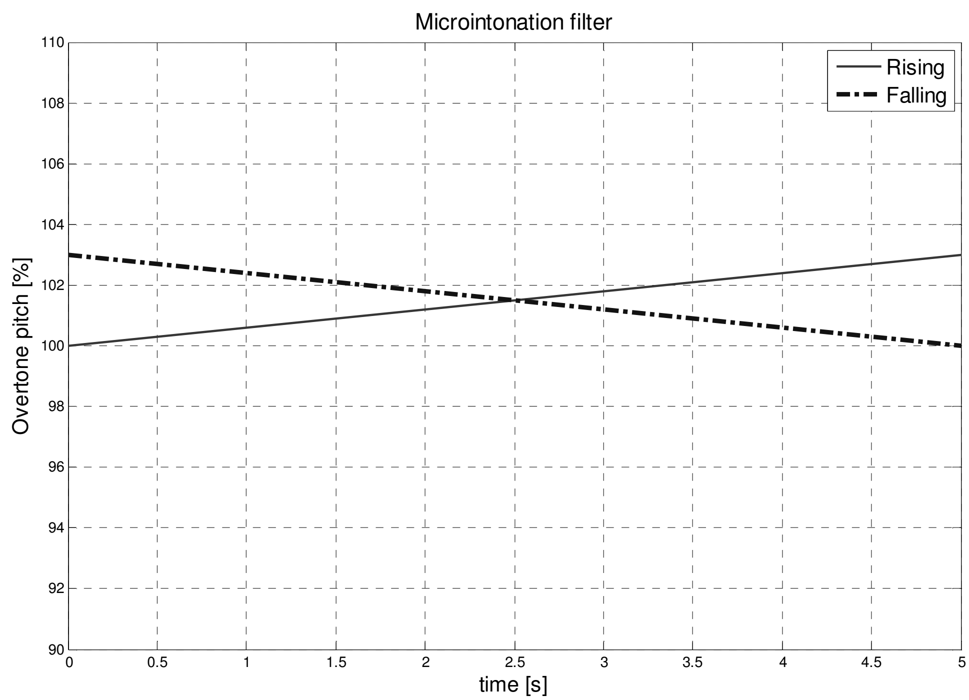

Figure 3.10: Rising respectively falling microintonation.

Sound 3 – 2 % flat
The overtone of the harmonic interval is increased in pitch by 2%.

Sound 4 – 3 % flat (1/4 of at tone step)
The overtone of the harmonic interval is increased in pitch by 3%.

Because of the fact that only sinusoidal intervals will be used when testing microintonation, it is likely that the 2- and 3 % flat intervals will give no results at all for most people. Musically trained people might hear the flat intervals because they are used to hear sharp intervals, but the general public will probably not. The rising and falling microintonation however, is hypothetically believed to be very valence effective. A rising microintonation will be perceived as happier, while the falling microintonation will be perceived as sadder.

3.3 Hypothesis Conclusions

According to the hypothesis, as has been pointed out before, most of the sounds will dominantly be effective on activation. Here follows a short summary of the acoustic parameters and musical sounds that will be used in the tests and how they will be used.

3.3.1 Overview of Acoustic Parameter and Musical Sound Influence

As can be read in table 3.2 and table 3.1 there are a few acoustic parameters that very likely will affect both valence and activity. This can be very useful when trying to "move the emotion diagonally" in a valence-activity graph.

Table 3.2: Acoustic parameter variation in the test designs.

Utilization cue:	**Levels** 1	2	3	4	5
Background noise (A)	Little				Much
Ritardando (A)	Little				Large
Sound Level (A)	Low				High
Sound Level Variability (V)	Little				Large
Articulation (A)	Staccato				Legato
Mean Tempo (A)	Slow				Fast
Tempo Variability (A & V)	Little				Large
Tone Attack (A)	Fast				Slow
Vibrato (A)	Shallow-Slow	Shallow-Fast	Avarage	Deep-Slow	Deep-Fast
A = Activation affective. V = Valence affective					

The harmonic intervals will hypothetically influence both activation and valence perception (Table 3.3).

Table 3.3: Intervals tested for the musical sounds.

Utilization cue:	**Harmonics** C	CDb	CD	CEb	CE	CF	CGb	CG	CAb	CA	CBb	CB	CC
Sinusoidal Intervals (A & V)	X	X	X	X	X	X	X	X	X	X	X	X	X
String Intervals (A & V)	X	X	X	X	X	X	X	X	X	X	X	X	X
Microintonation (A & V)		X	X	X	X	X	X	X	X	X	X	X	X
A = Activation affective. V = Valence affective													

4 Designing the sounds

Counting all the acoustic parameters and the musical sounds, a total of 261 sounds need to be designed. There are nine acoustic parameters, 13 sinusoidal intervals and 13 string intervals, all in three pitches, and an additional 48 sounds for the microintonation cue. The microintonation cue will however only be tested in one pitch (*Pitch 6*) to reduce the number of sounds.

4.1 MATLAB Designs

The sinusoidal sounds, which include all sounds except the string intervals, were created in MATLAB.

4.1.1 Acoustic Parameters

These do not include *Background Noise* and *Vibrato*. They are described in the subchapters below.

The acoustic parameters all have the same base, a five second sinusoidal C (Pitch 5, 6 or 7) with amplitude 1, on top of which a pattern with the property of the acoustic parameter was placed. The patterns are the very same found in 3.1. Moreover, a Hanning window of five milliseconds was added to the beginning and end of each sound burst, to eliminate click distortion.

4.1.2 Background Noise

The noise was produced by creating a five second string with random numbers between 1 and -1. The string was then multiplied with 0.1, 0.2, 0.3, 0.4 respectively 0.5 and added to the sinusoidal C:s.

4.1.3 Vibrato

As described in 3.1.10 the *Vibrato* have two factors determining its characteristic, the vibration frequency and amplitude. The form of the vibrato sound is easiest described by the formula used in MATLAB to create the sounds.

Equation 3: Vibrato formula.

$$C_{Vibrato} = \sin(2 \cdot \pi \cdot (f_{fundamental} + A_{Vibrato} \cdot \sin(2 \cdot \pi \cdot f_{vibrato} \cdot t)) \cdot t)$$

$C_{Vibrato}$: Signal of the vibrating tone

$f_{fundamental}$: Fundamental frequency of the sound (the mean frequency) in Hertz

$A_{Vibrato}$: Amplitude of the vibrato in $\%/100$ of vibrating tone's amplitude

$f_{Vibrato}$: Frequency of the vibrato in Hertz

t : Time length of the sound in seconds

4.1.4 Sinusoidal Intervals

When designing the sinusoidal intervals a C with amplitude 1 was also used, on top of which its harmonic interval overtone was simply added. The sound was then normalized to one.

4.1.5 Microintonation

The microintonation sounds were created similarly to the sinusoidal intervals. The difference was that, instead of “normal” harmonic interval overtones, pitch modulated overtones were added. Rising and falling microintonation simply contain overtones linearly pitch shifting upwards respectively downwards. In the rising microintonation the overtone goes from a sharp interval to a 3 % increase. In the falling microintonation the overtone goes from a 3 % increase to a sharp interval. The pitch shift can be seen in figure 4.1 (This figure also appears in chapter 3.2.2).

The flat intervals are basically the same as the sinusoidal intervals, only here the interval overtones were shifted up in frequency by 2 respectively 3 %.

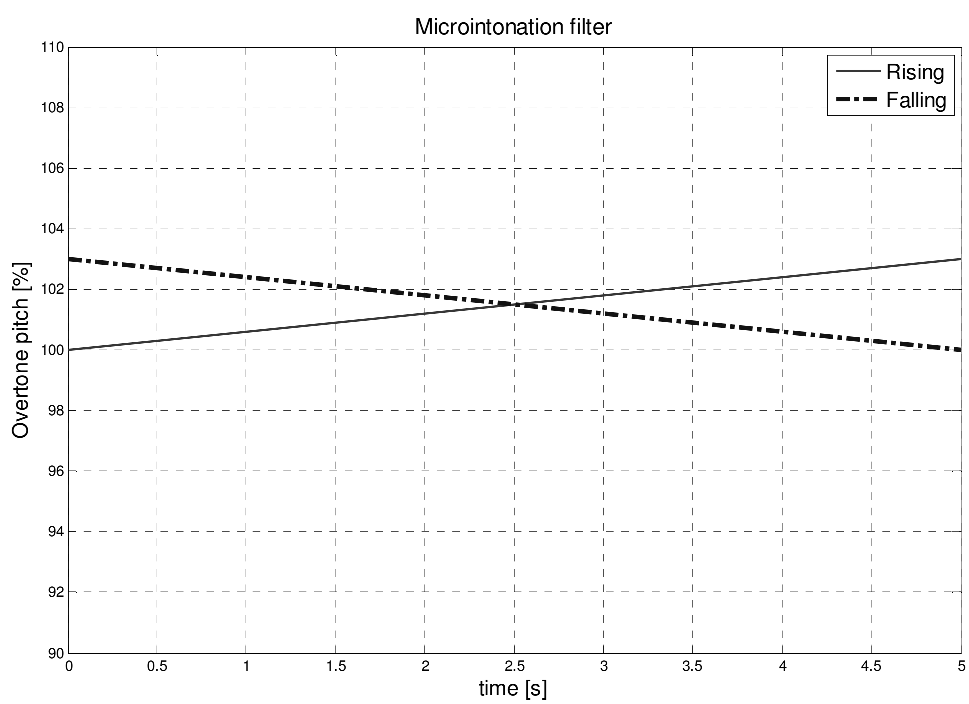

Figure 4.1: Rising respectively falling microintonation.

5 Listening Tests 1

The investigation of the objectives of this thesis was divided into two stages. This first stage is designed to give large outputs. The meaning of 'large output' is to design the test in such a way that the subjected persons will make larger distinctions between the sounds. The large outputs are needed to get an overview of the acoustic parameters and harmonic intervals. To get these large outputs, the listening test persons were asked to rate how they thought sound sounded, in opposite to how it made them feel (This is also the distinction between 'perception of emotion' and 'emotional perception').

Four sets of sounds were used, due to the fact that the amount of sounds was too great to only perform only one test. Part 1 and Part 2 contained the same set of sounds with the exception of the fact that the sounds in Part 2 was played in the opposite order as Part 1. This was done to eliminate any effects of tiring the listening persons. Part 3 and 4 were performed analogically, but with another set of sounds. The same person was allowed to take both Test 1 and Test 2, but not Part 1 and 2 or Part 3 and 4.

Figure 5.1: The listening test.

The listening test was performed in groups of 15 persons per test in the teaching lab in the Division of Applied Acoustics, Chalmers University of Technology. (Figure 5.1) The subjects had two tasks to perform. They were to answer on a SAM (Self-Assessment Manikin, see [8]) scale from A – I, how activating they thought the sound sounded in one column, and how happy or sad (valence) they thought the sound sounded in another column. The SAM figures used in the test are shown in figure 5.2 and figure 5.3.

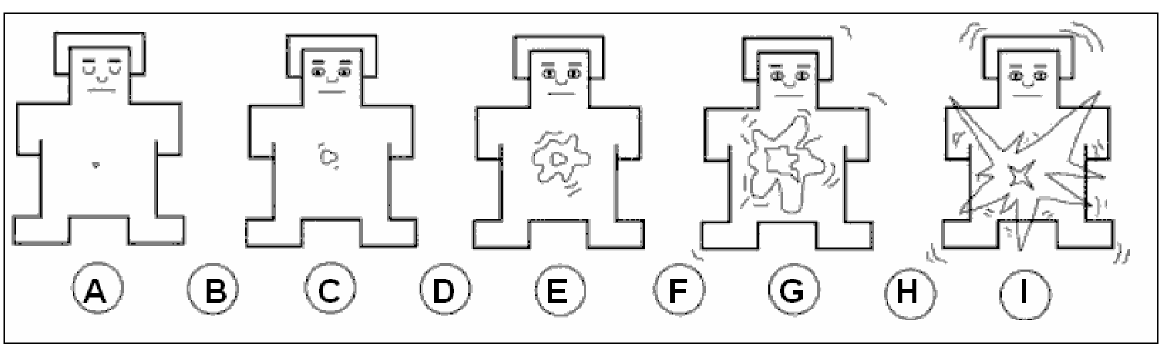

Figure 5.2: SAM figure for activation.

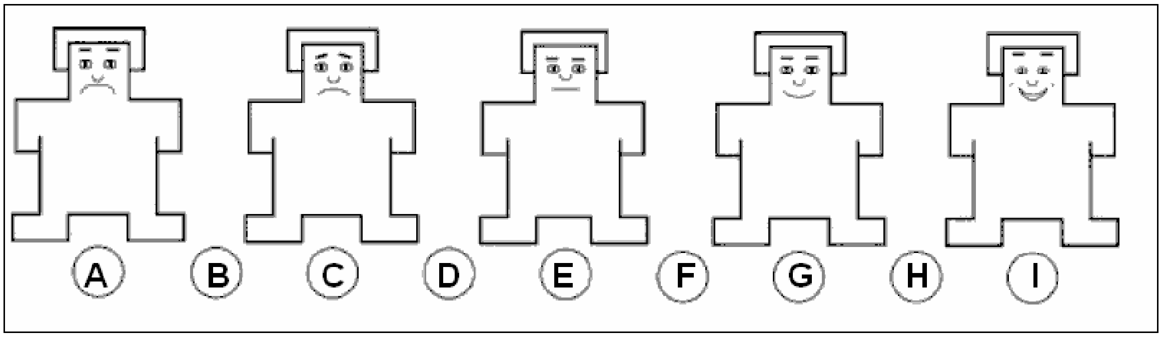

Figure 5.3: SAM figure for valence.

After approximately half the sounds were played there was a short break to clear the participant's minds and get some air. The subjects were asked not to discuss the test in any way during the break. The listening test persons were furthermore asked to answer a questionnaire to denote age, gender, nationality and prior musical experience. These answers were to be used to explain any outstanding answers. The questionnaire was answered anonymously. A copy of the listening test questionnaire can be found in the appendix. The properties of the test persons are shown in table 5.1 below.

Table 5.1: The characteristics of the test persons.

Participants					
		Sex [%]		Mean Age	St. Dev.
	n	Male	Female	[Years]	[Years]
Test 1	29	59	41	26.9	5.4
Test 2	28	61	39	25.3	5.3

5.1 Listening Test Setup

All sounds designed had the file format *.wav* and to reproduce them for the test, a PC with the software WMP (Windows Media Player) was used. WMP's built-in equalizer (EQ) was turned off. The digital signal from the PC's soundcard was converted in the pre amplifier and sent to an EQ where it was loudness compensated with an inverted A-weighting curve in third octave bands from 80 Hz to 25 kHz.

Figure 5.4: Amplifier and EQ of the listening test.

The loudness compensation was used to rule out the influence of any frequencies being more or less loud than others and in that way influence the results.

From the EQ the signal was further amplified with a NAD amplifier and distributed to headphones. To eliminate any extra background noise the computer was put in a separate room from where the listening test took place. The amplifier and EQ are shown in figure 5.4 and the full setup is shown in figure 5.5.

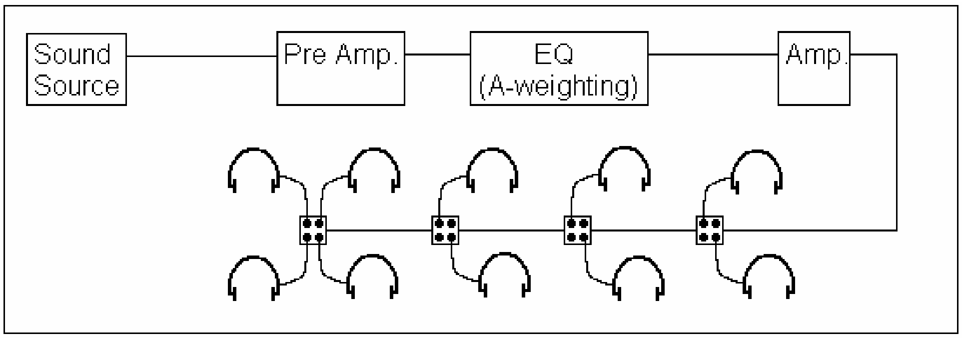

Figure 5.5: Listening test setup.

5.1.1 Equipment

Computer	– DELL Dimension	– XPS T500
Operative System	– Windows NT	
Software	– Windows Media Player	– Version: 9.00.00.3349
Hardware	– Digital Soundcard	– RME DIGI 96/Pro
Pre amplifier	– Lucid	– DA 9624, 24 Bit D/A Converter
Equalizer	– Technics	– Stereo Graphic Equalizer, SH-8065
Amplifier	– NAD	– Stereo Integrated Amplifier 310
Headphones	– Sennheiser	– HD 414

5.1.2 Sennheiser HD414

The headphone's frequency response (FR) was measured, unfortunately after the first test was performed, and an increase by 5 dB was discovered in the region from 1 kHz – 2.5 kHz (Figure 5.6). This means that, for the harmonic interval sounds, the interval tones in pitch 7 are stronger than the fundamental tone.

When listening to these sounds one can hear a change in the sound. However, the hearable sound change is in pitch, i.e. it sounds like the interval has a higher pitch than it really does. The color of the interval has not disappeared. Therefore one could expect the same reaction to the sound, but with a small extra affect by pitch.

The A-weighting pulls the curve down a bit, but the SPL increase is still present (Figure 5.7).

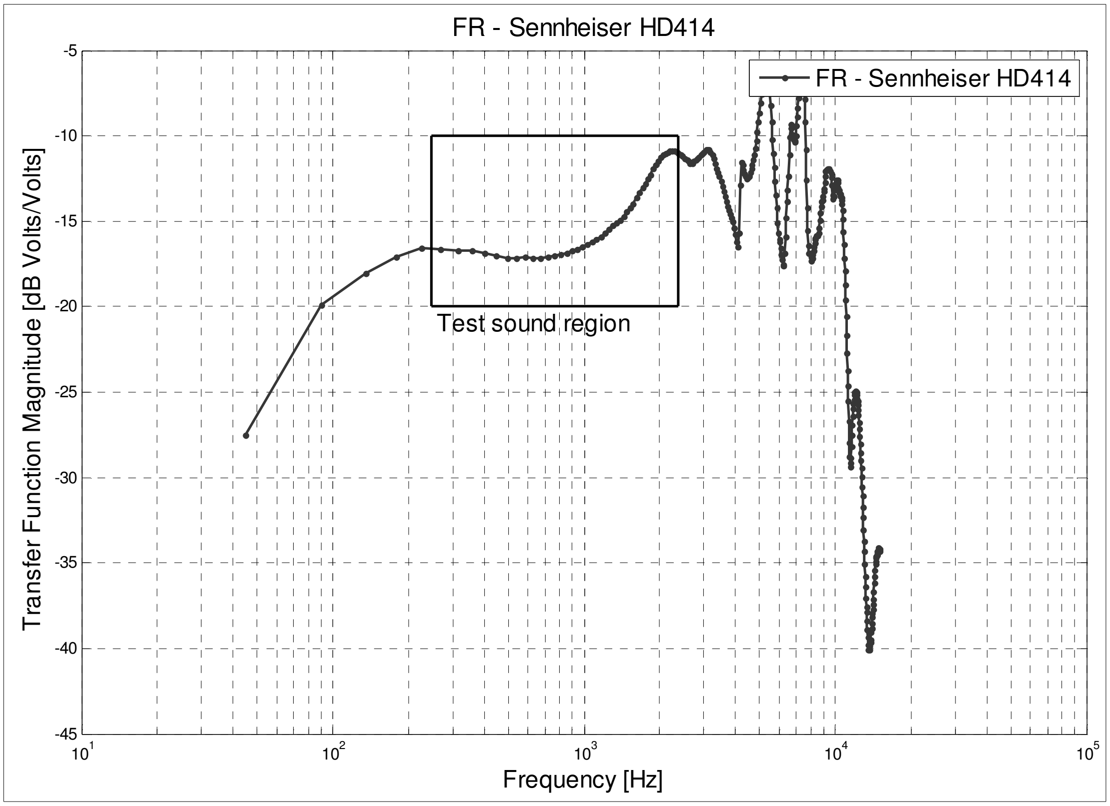

Figure 5.6: Frequency response of the Sennheiser headphones.

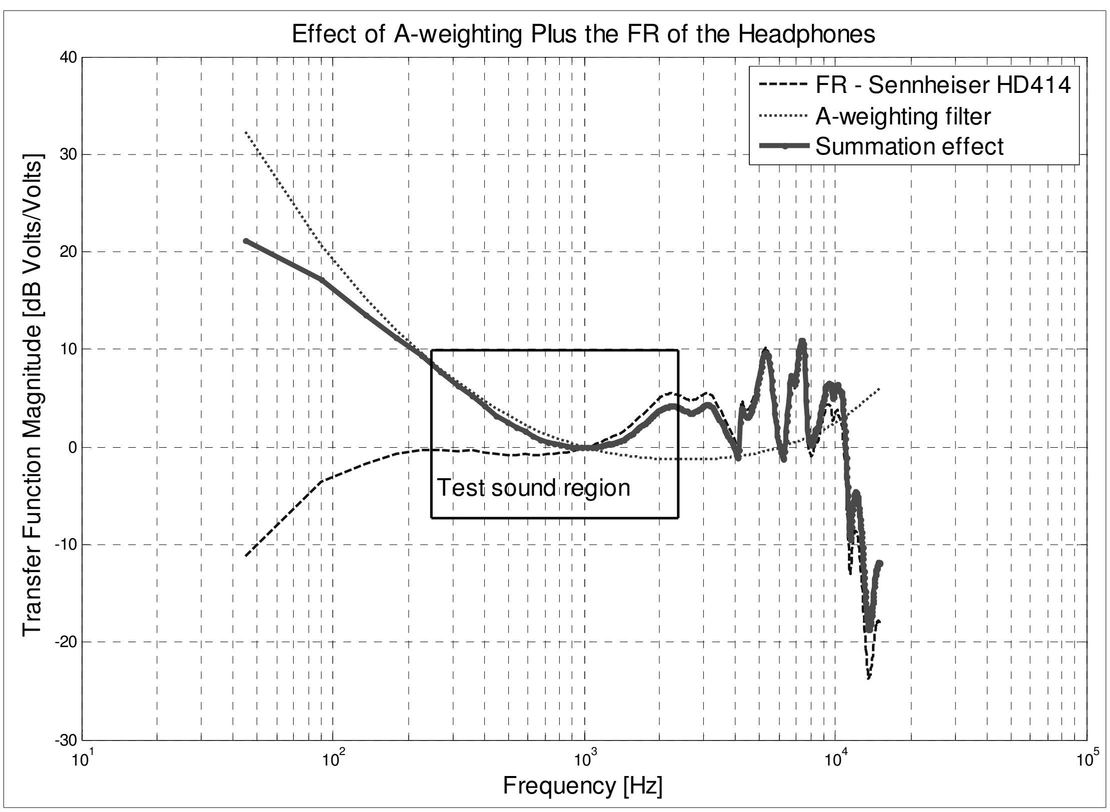

Figure 5.7: The combined effect of the A-weighting plus the FR of the headphones.

6 Results and Analysis – Test 1

All results from the listening tests have been plotted and analyzed using SPSS. What is wanted are responses that preferably are statistically significantly different between the sounds and also show some kind of linearity between the answer groups. If the answer groups show no significant difference they are considered the same answer. This could mean that the sounds were too alike to observe an influence of the used acoustic parameter.

Some of the sounds do not show both linearity in the figures and statistically significant difference. However, it might still possible to draw conclusions from the figures if the tendencies in the same are clear. The answers from the listening test will be plotted on the X- and Y-axes as shown in figure 6.1. However, the letters A through I are replaced with the respective number between 1 and 9 for calculation purposes.

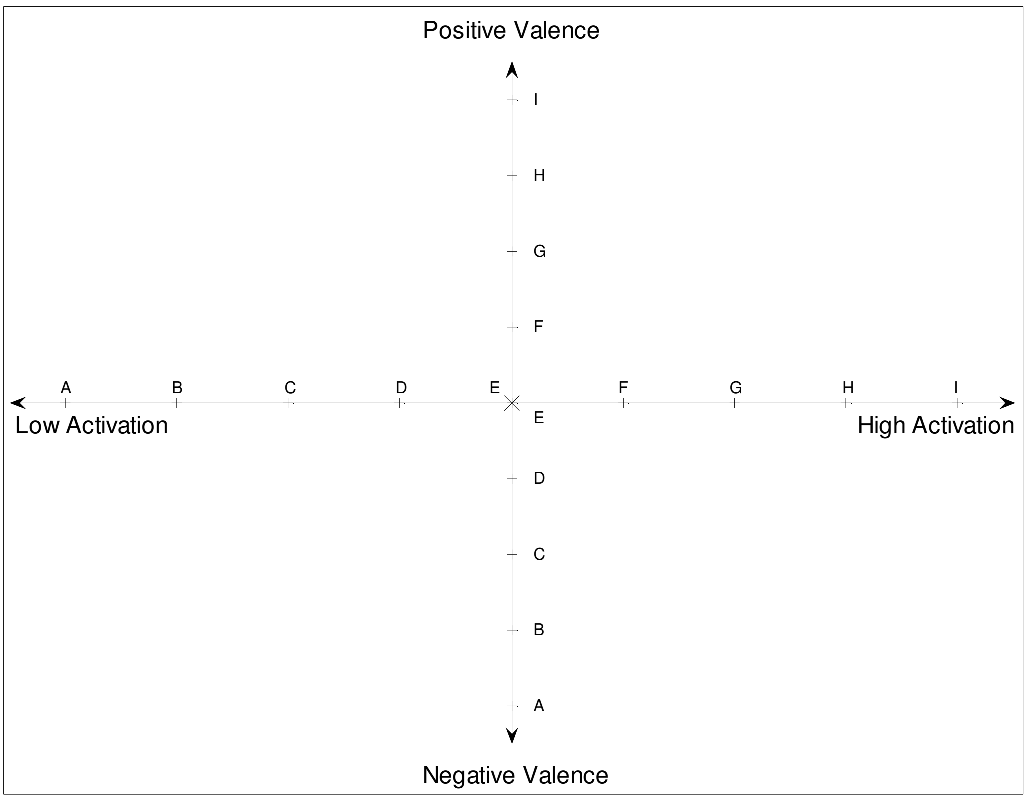

Figure 6.1: Plot of answer presentation.

No numbers will however be shown in the result figures in the following chapters. It is the approximate placement of the mean values and the relative difference between the same that is of interest. Exact numbers are irrelevant.

6.1.1 Statistical Treatment of Data

The results of the listening test should preferably show statistically significant differences. Therefore all answers from the listening test have been compared with SPSS

[11]. SPSS was used to make a multiple ANOVA comparison and shows the significance of the answer groups compared to each other. The hope is for the answer groups to show significant difference, i.e. the sounds should not be the same. A confidence interval of 95% was used. This means that, if the significance between the sounds is less than 5%, they will be considered significantly different and would then not be the same answer to the acoustic parameter or musical sound (Equation 2). Besides from significance, the output from SPSS gives the mean value and standard deviations.

6.1.2 Significance

The significant differences in the following chapters, presents pair wise comparisons between the levels in the sounds. The output is presented as a table comparing 1 to 2, 1 to 3, etc. the numbers represent the sounds in the order they were entered into SPSS. The sounds are entered in SPSS in level-order, making SPSS naming them in the same order as they are designed, i.e. Level 1 = sound 1 in SPSS, etc. Table 6.1 shows more clearly how it works.

Table 6.1: SPSS's output presentation.

	SPSS #
Level 1	1
Level 2	2
Level 3	3
Level 4	4
Level 5	5

		Significance
1	2	x.xxx
	3	x.xxx
	4	x.xxx
	5	x.xxx
2	3	x.xxx
	4	x.xxx
	5	x.xxx
3	4	x.xxx
	5	x.xxx
4	5	x.xxx

Equation 5: Significance (*p*)

$p > 0.05 \Rightarrow$ No significant difference $\qquad p \leq 0.05 \Rightarrow$ Significantly different

6.2 Acoustic Parameters

To get an overview of what affect each sound had on the perception of emotion, the sounds will be analyzed individually.

6.2.1 Pitch

All results show an increase in both activation and valence perception between the three different pitches, which gives a very clear indication of the pitch influence on the listener. (This is important to have in mind when analyzing the other acoustic parameters, since they all have been tested in three pitches.)

Table 6.2: Significance between Pitch 5, 6 and 7.

Sounds		Sig. A	Sig. V
1	2	**0.000**	**0.002**
	3	**0.000**	**0.002**
2	3	**0.000**	**0.024**

To get a general idea, the results from each pitch of every acoustic parameter for each test person have been added to calculate a mean value. New mean values, standard deviations and the significance levels of these mean values were then calculated. The new mean values and standard deviations are plotted in figure 6.2

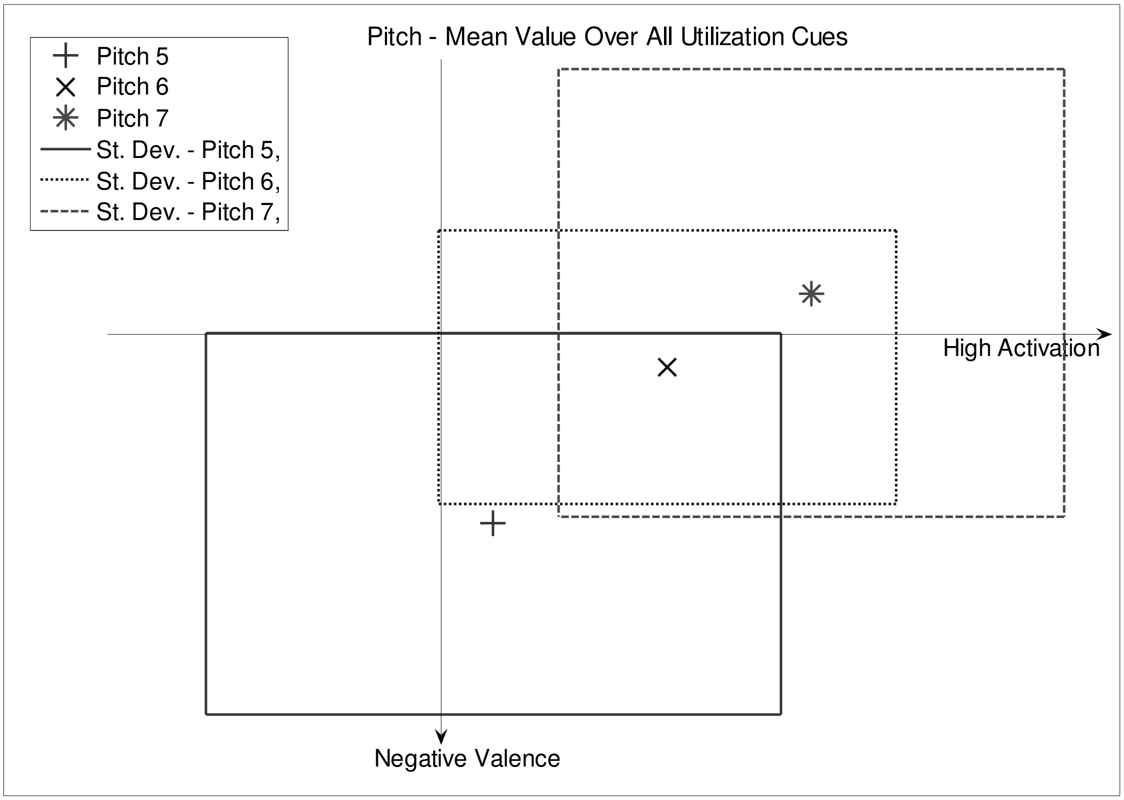

Figure 6.2: Results of increased pitch.

The significance levels between the three pitches are nonexistent (Table 6.2). This means that we can with confidence say that an increase in pitch will give us higher activation and more positive valence.

Looking at the results of *Pitch*, the linearity appears striking. However, they do not have to be linear. With only three points it is impossible to say whether they are linear or logarithmic or neither. More tests must be done.

6.2.2 Background Noise

When calculating the significance levels of the answers of *Background Noise*, the only significant difference was in activation, found only between level 1 and all other levels among the sounds in Pitch 7 (Table 6.3). This looks however, judging from the figure, like it only is a large random deviation. The influence on valence could still be discussed, even though no significant difference could be found.

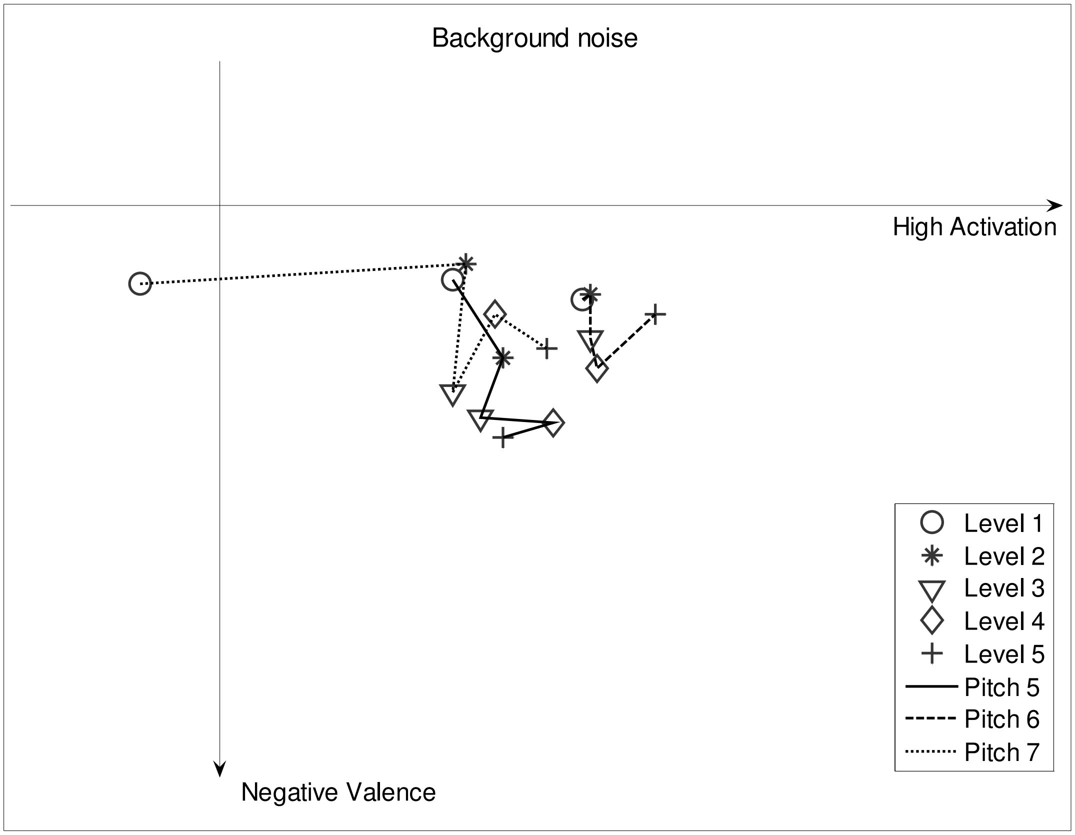

Figure 6.3: Results of increased background noise.

Figure 6.3 shows a slight tendency of being valence effective (except for Level 5 in Pitch 7). If larger and/or more level steps had been used between the sounds, a clearer difference would probably have appeared.

Table 6.3: Significance of the background noise test for the three pitches.

Sounds		Sig. Pitch 5		Sig. Pitch 6		Sig. Pitch 7	
		A	V	A	V	A	V
1	2	1.000	1.000	1.000	1.000	**0.018**	1.000
	3	1.000	0.151	1.000	1.000	**0.016**	0.299
	4	1.000	0.284	1.000	1.000	**0.009**	1.000
	5	1.000	0.167	0.961	1.000	**0.000**	1.000
2	3	1.000	1.000	1.000	1.000	1.000	0.275
	4	1.000	1.000	1.000	0.701	1.000	1.000
	5	1.000	1.000	1.000	1.000	1.000	0.808
3	4	1.000	1.000	1.000	1.000	1.000	0.578
	5	1.000	1.000	1.000	1.000	0.965	1.000
4	5	1.000	1.000	1.000	1.000	1.000	1.000

6.2.3 Sound Level

The answers from the test on *Sound Level* show one thing very clearly. Figure 6.4 and the significance levels in table 6.4 give us unarguable result. Higher sound level is perceived as having higher activation, and/or the other way around, lower sound level is perceived as having lower activation.

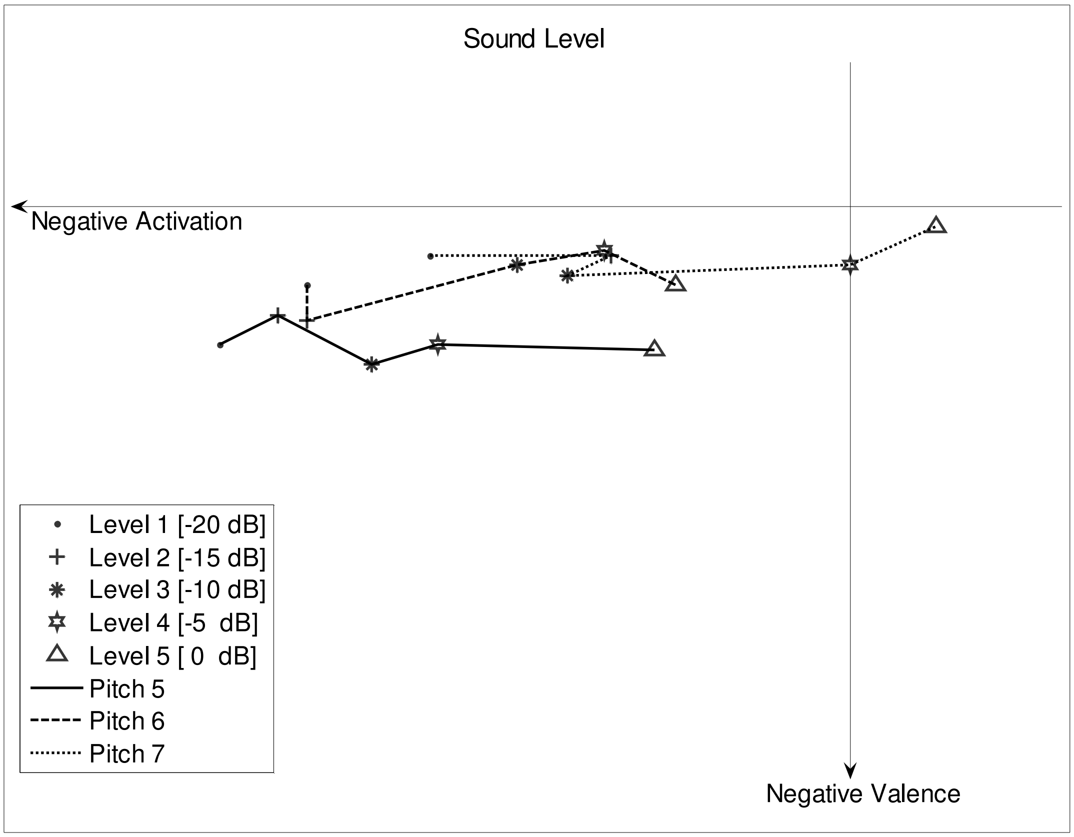

Figure 6.4: Results of increased sound level.

Table 6.4: Significance of the sound level test for the three pitches.

Sounds		Sig. Pitch 5		Sig. Pitch 6		Sig. Pitch 7	
		A	V	A	V	A	V
1	2	1.000	1.000	1.000	1.000	0.300	1.000
	3	0.199	1.000	**0.035**	1.000	0.418	1.000
	4	**0.031**	1.000	**0.005**	1.000	**0.000**	1.000
	5	**0.000**	1.000	**0.000**	1.000	**0.000**	1.000
2	3	1.000	1.000	**0.012**	1.000	1.000	1.000
	4	0.266	1.000	**0.000**	1.000	**0.011**	1.000
	5	**0.000**	1.000	**0.000**	1.000	**0.006**	1.000
3	4	1.000	1.000	0.831	1.000	**0.002**	1.000
	5	**0.001**	1.000	0.123	1.000	**0.000**	1.000
4	5	**0.012**	1.000	1.000	1.000	1.000	1.000

6.2.4 Articulation

Judging from the mean values, when going from a staccato to a legato articulation, a tendency of increasing activation appears. However, the significance levels between the five groups are too high. This would mean that the answers are too similar to make a distinct separation between them.

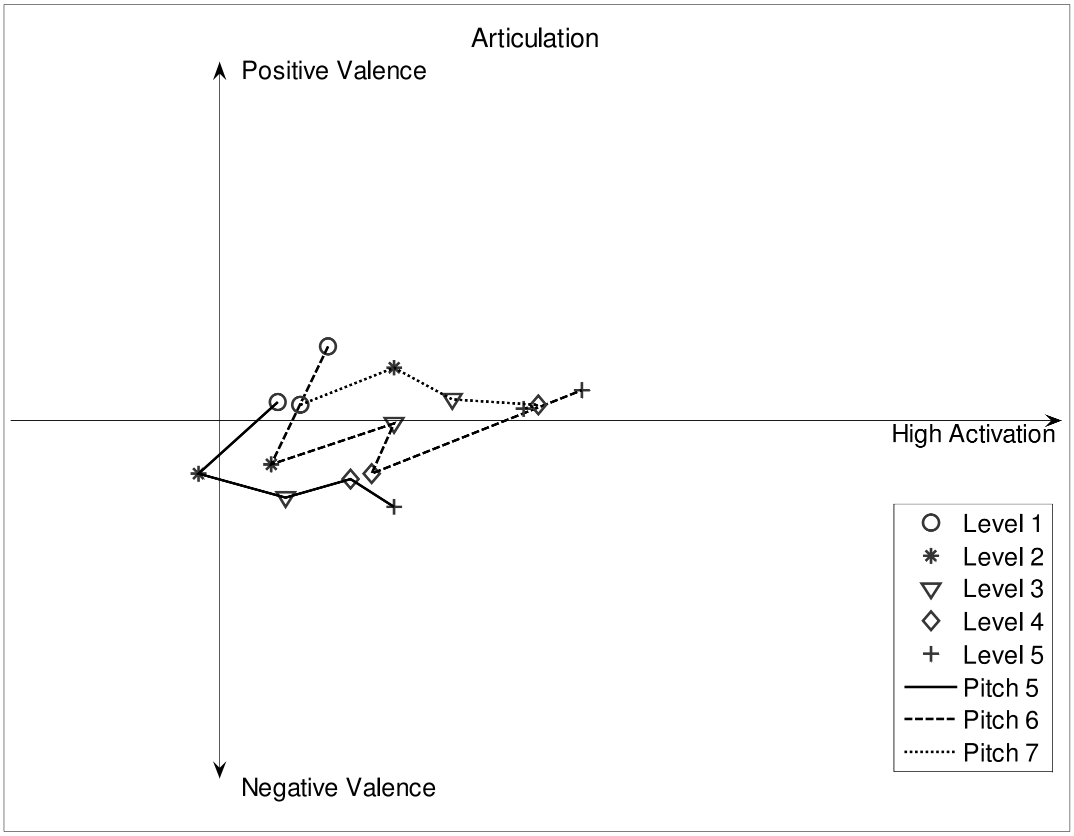

Figure 6.5: Results of the articulation, going from staccato to legato.

Table 6.5: Significance of the articulation test for the three pitches.

Sounds		Sig. Pitch 5		Sig. Pitch 6		Sig. Pitch 7	
		A	V	A	V	A	V
1	2	1.000	0.142	1.000	**0.002**	0.792	1.000
	3	1.000	**0.033**	1.000	0.093	0.100	1.000
	4	1.000	0.424	1.000	**0.000**	**0.004**	1.000
	5	1.000	0.067	**0.002**	1.000	0.071	1.000
2	3	1.000	1.000	1.000	1.000	1.000	1.000
	4	0.285	1.000	1.000	1.000	0.053	1.000
	5	**0.032**	1.000	**0.002**	0.898	1.000	1.000
3	4	1.000	1.000	1.000	0.691	0.628	1.000
	5	1.000	1.000	**0.004**	1.000	1.000	1.000
4	5	1.000	1.000	**0.002**	0.072	1.000	1.000

6.2.5 Mean Tempo

The results of the *Mean Tempo* sounds also show clear tendencies. The perception of activity of the subjected persons seems to be increasing as the mean tempo is increased. Although the significance level is not unambiguous, it is still legible. Valence on the other hand seems unaffected by mean tempo.

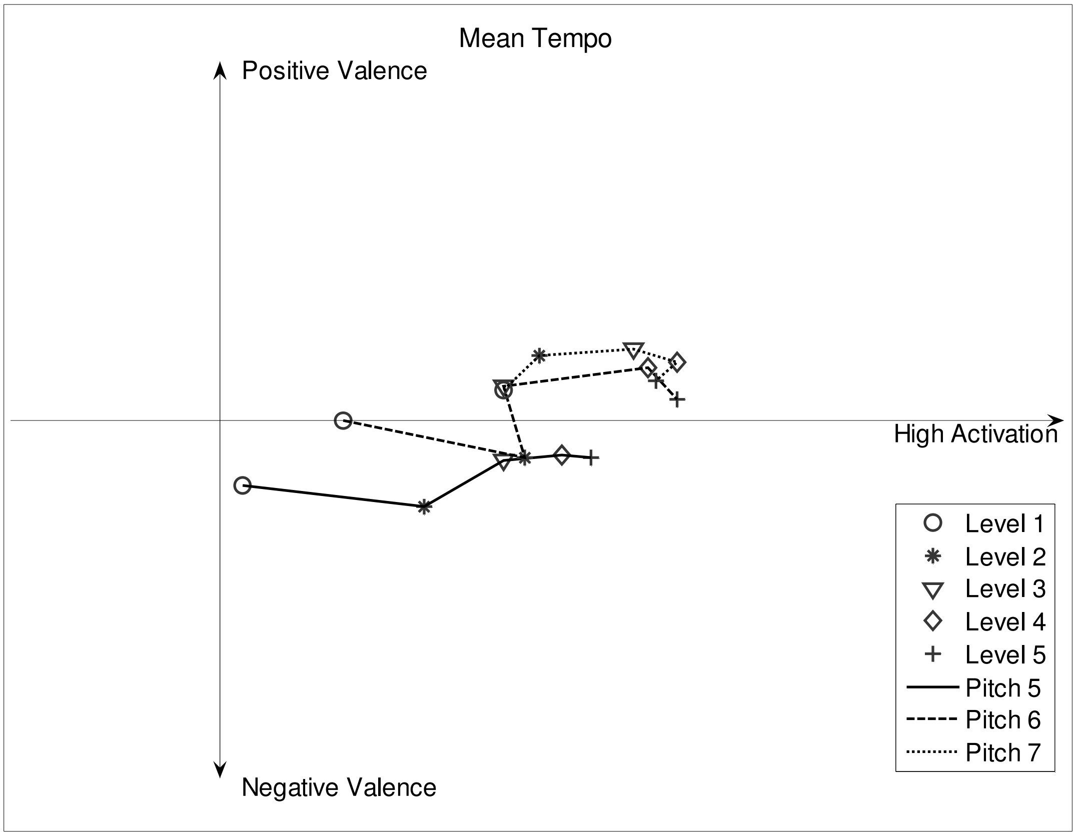

Figure 6.6: Results of increased mean tempo.

Table 6.6: Significance of the mean tempo test for the three pitches.

Sounds		Sig. Pitch 5 A	Sig. Pitch 5 V	Sig. Pitch 6 A	Sig. Pitch 6 V	Sig. Pitch 7 A	Sig. Pitch 7 V
1	2	0.071	1.000	0.071	1.000	1.000	1.000
	3	**0.002**	1.000	**0.018**	1.000	**0.006**	1.000
	4	**0.000**	1.000	**0.000**	0.640	**0.001**	1.000
	5	**0.000**	1.000	**0.000**	1.000	0.503	1.000
2	3	1.000	0.701	1.000	**0.018**	0.453	1.000
	4	0.092	0.541	0.574	0.093	0.139	1.000
	5	**0.031**	0.691	0.125	0.759	1.000	1.000
3	4	1.000	1.000	0.207	1.000	1.000	1.000
	5	0.497	1.000	0.057	1.000	1.000	1.000
4	5	1.000	1.000	1.000	1.000	1.000	1.000

6.2.6 Tempo Variability

Although nothing can be read from the significance levels in table 6.7, a very small tendency of influence on both valence and activation is shown in the mean values in figure 6.7.

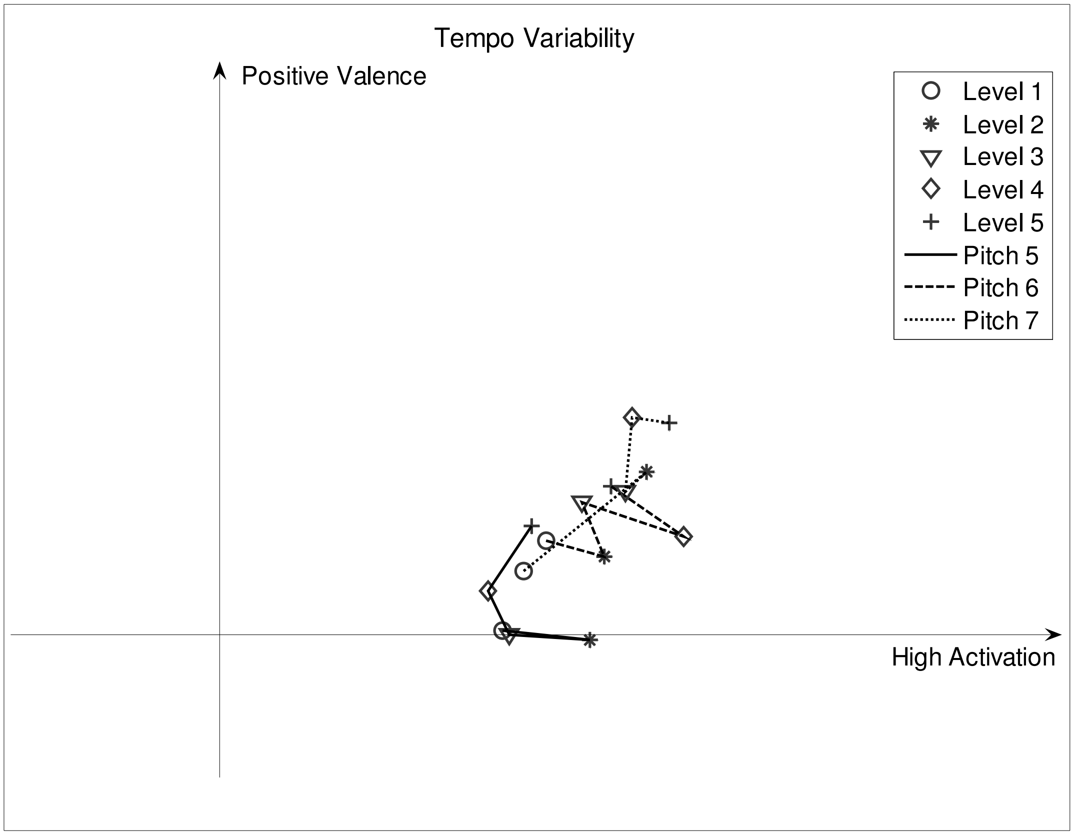

Figure 6.7: Results of increased tempo variability.

Table 6.7: Significance of the tempo variability test for the three pitches.

Sounds		Sig. Pitch 5		Sig. Pitch 6		Sig. Pitch 7	
		A	V	A	V	A	V
1	2	1.000	1.000	1.000	1.000	0.267	0.839
	3	1.000	1.000	1.000	1.000	1.000	0.653
	4	1.000	1.000	0.055	1.000	1.000	0.066
	5	1.000	0.303	1.000	1.000	0.111	0.049
2	3	1.000	1.000	1.000	1.000	1.000	1.000
	4	0.797	1.000	1.000	1.000	1.000	1.000
	5	1.000	0.635	1.000	1.000	1.000	1.000
3	4	1.000	1.000	0.748	1.000	1.000	1.000
	5	1.000	0.538	1.000	1.000	1.000	1.000
4	5	1.000	1.000	0.766	1.000	1.000	1.000

6.2.7 Vibrato

If you remember chapter 3.1.10, you are aware of that the vibrato levels were not linearly designed. Level 1 and 2 had the same vibration amplitude (VA) but different vibration frequency (VF), so did Level 4 and 5. Level 3 was a mean in both VA and VF.

In the result figures figure 6.8 and figure 6.9 one can see differences between Level 1, 2, 4 and 5. A VF increase seems to result in an increased activation, while a VA increase seems to result in both a valence and an activation increase.

The VF shows to be influencing activation ratings but neither VF nor VA has any influence on valence. It seems however that VF has lesser influence on higher frequencies. This could have to do with the larger separation between the fundamental tone and its closest semitone and could point to a linear ratio between VF and the fundamental frequency.

The distinction between different VA:s influence on activation is not as convincing, even though a tendency can be read from figures, which also is concurred by the significance levels between Level 2 and 5, in table 6.8.

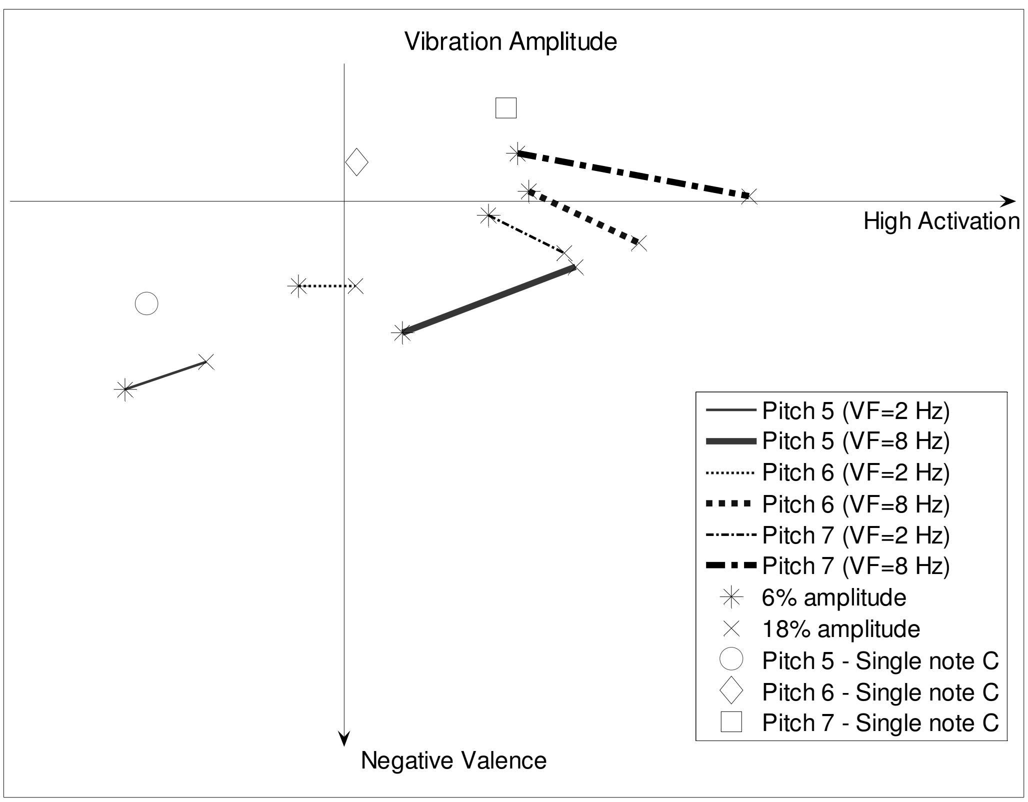

Figure 6.8: Results of increased vibration amplitude.

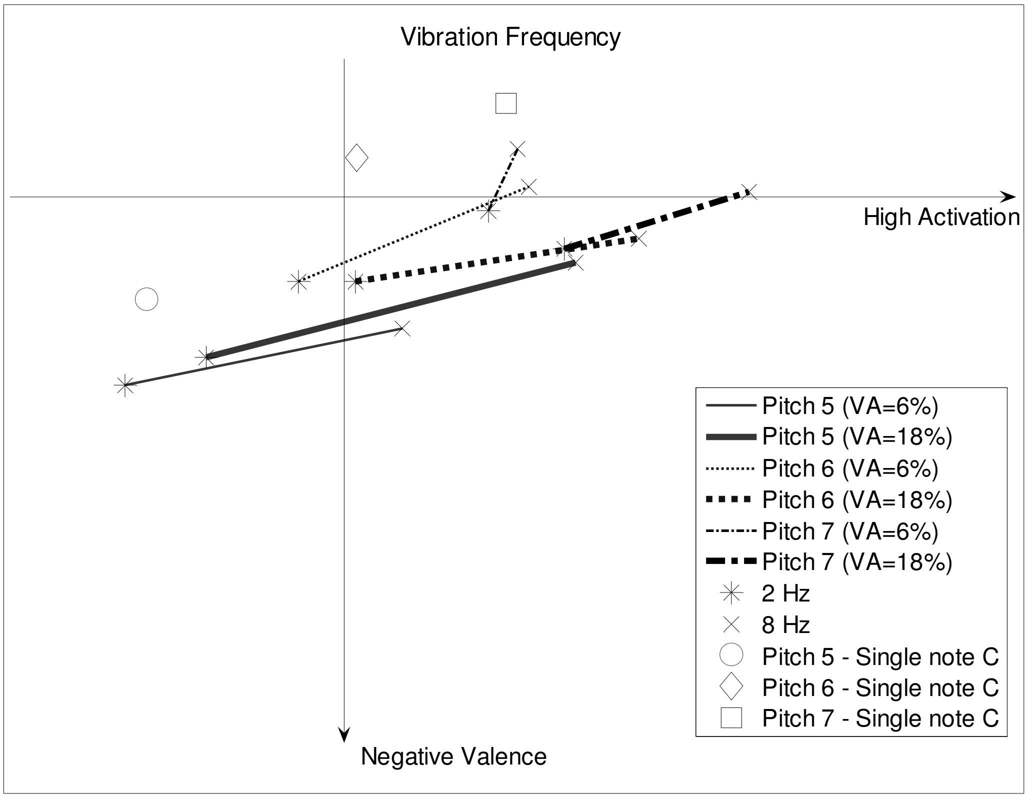

Figure 6.9: Results of increased vibration frequency.

Table 6.8: Significance of the vibrato test for the three pitches.

			Significance					
	Level		Pitch 5A	Pitch 6A	Pitch 7A	Pitch 5V	Pitch 6V	Pitch 7V
VF	1	2	**0.001**	**0.000**	1.000	1.000	0.549	1.000
	4	5	**0.000**	**0.000**	**0.010**	1.000	1.000	1.000
VA	1	4	0.996	1.000	0.734	1.000	1.000	1.000
	2	5	0.086	0.158	**0.006**	1.000	1.000	1.000

6.3 Musical Sounds

6.3.1 Harmonic Intervals

What really is interesting is how the harmonic intervals differ from a pure tone. If one could know that it would be of great assistance when designing sound. For example, if an existing signal gives the “wrong” response one could use a harmonic interval to change the wrong response to the desired response.

First if we look only at how the intervals behave within its separate group (sinusoidal respectively strings). The only interval standing out is the chromatic semitone (CDb). The chromatic semitone seems to be highly effective on both activation and valence, giving higher activation and more negative valence. It is also very clear from figure 6.10 that the string intervals, which contain plenty of natural overtones, have a more activating and more negative valence influence.

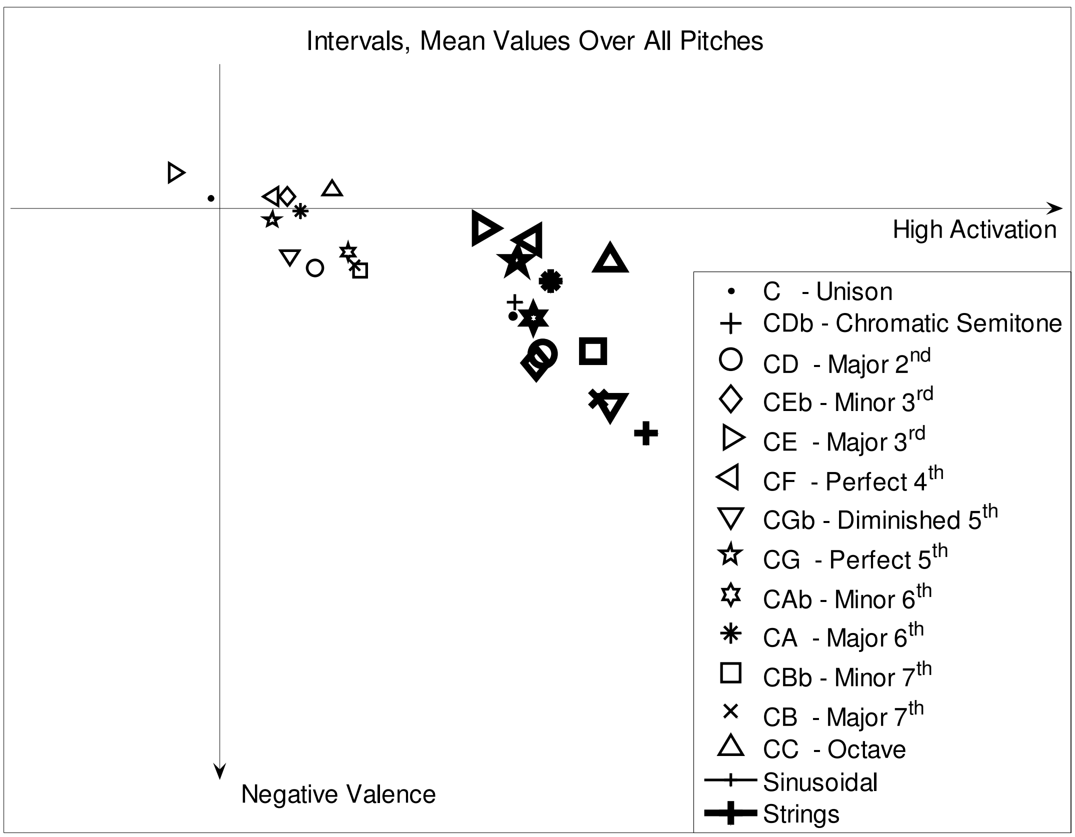

Figure 6.10: Results of the harmonic intervals.

Just by taking one look at figure 6.10, the results of the string intervals seem to be similar to the results of sinusoidal intervals. One can see that there are several intervals making similar moves from the fundamental tone C for the two sound types. (CDb, CD, CE, CGb, CAb, CBb, CB and CC). This suggests that, even though the groups are individually not significantly different, an interval has a certain affect on the subjected person's perception of how it sounds. Furthermore, one can see that the perfect consonant, imperfect consonant and dissonant, intervals are grouped together, with larger affect on negative valence as the interval gets more dissonant. There is also a very small tendency of more dissonant intervals to be more activating (see figure 6.11). Table 6.9 shows the intervals and the relative perception to a unison tone.

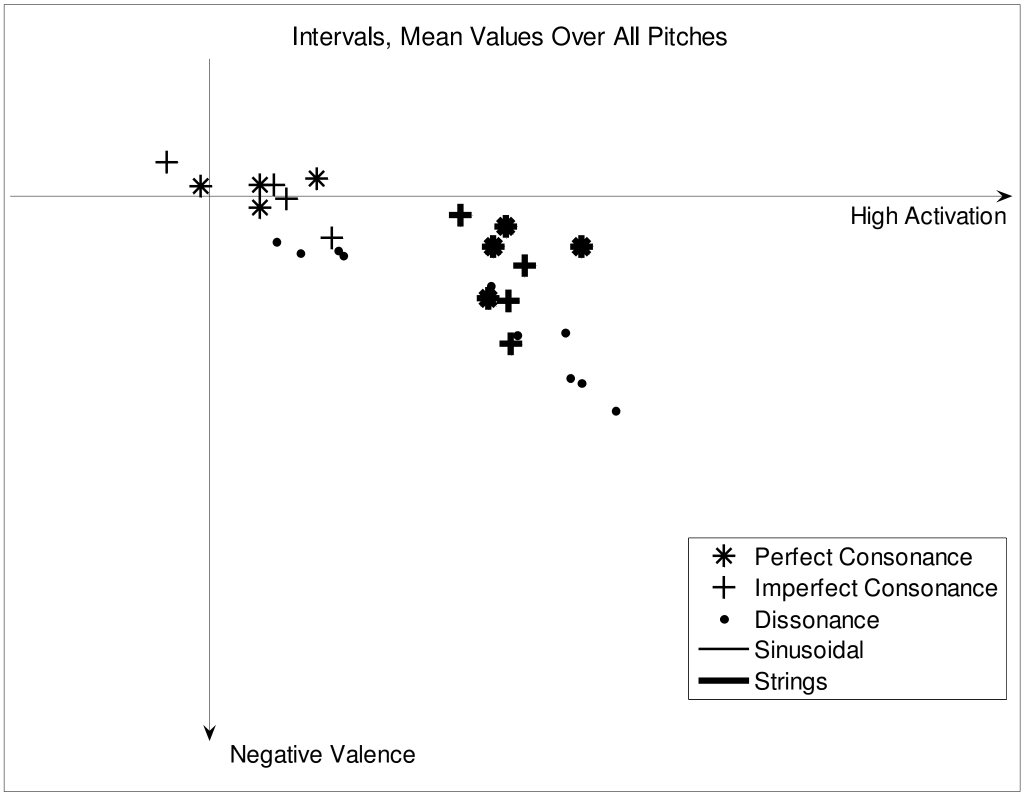

Figure 6.11: Reaction to consonance and dissonance.

Table 6.9: Difference between intervals and unison tone in percentages.

		Movement [%]				
		Activation		Valence		
		Sin.	Str.	Sin.	Str.	
Chromatic **semitone**	CDb	129.3	109.9	86.7	80.7	**Perfect Consonance**
Major **2nd**	CD	110.1	102.2	90.4	93.6	**Dissonance**
Minor **3rd**	CEb	107.5	107.7	100.2	92.2	**Imperfect Consonance**
Major **3rd**	CE	96.6	97.8	103.5	114.3	**Imperfect Consonance**
Perfect **4th**	CF	106.0	101.3	100.2	112.3	**Perfect Consonance**
Diminished **5th**	CGb	107.7	107.3	92.0	85.4	**Dissonance**
Perfect **5th**	CG	106.0	100.4	97.0	109.0	**Perfect Consonance**
Minor **6th**	CAb	113.2	101.5	92.5	99.4	**Imperfect Consonance**
Major **6th**	CA	108.7	102.8	98.1	105.6	**Imperfect Consonance**
Minor **7th**	CBb	114.4	106.0	89.9	94.1	**Dissonance**
Major **7th**	CB	113.9	106.3	90.6	86.3	**Dissonance**
Octave	CC	111.8	107.3	101.2	109.0	**Perfect Consonance**

6.3.2 Microintonation

The microintonation sounds between the different harmonic intervals showed no difference in significance levels nor in the figures, i.e. the answer group of CDb – Rising microintonation was no different from e.g. CE – Rising microintonation. The same goes for all four microintonation sounds, rising-, falling-, 2 % flat- and 3 % flat microintonation (these figures are not included in this thesis). Hence, to get a larger answer group the mean values for the four sounds was calculated over all intervals of each test person. In figure 6.12, these new mean value answer groups are plotted and the recalculated significance levels are shown in table 6.10. It turned out that the two flat intervals gave once again nothing. However, the rising and falling microintonation did.

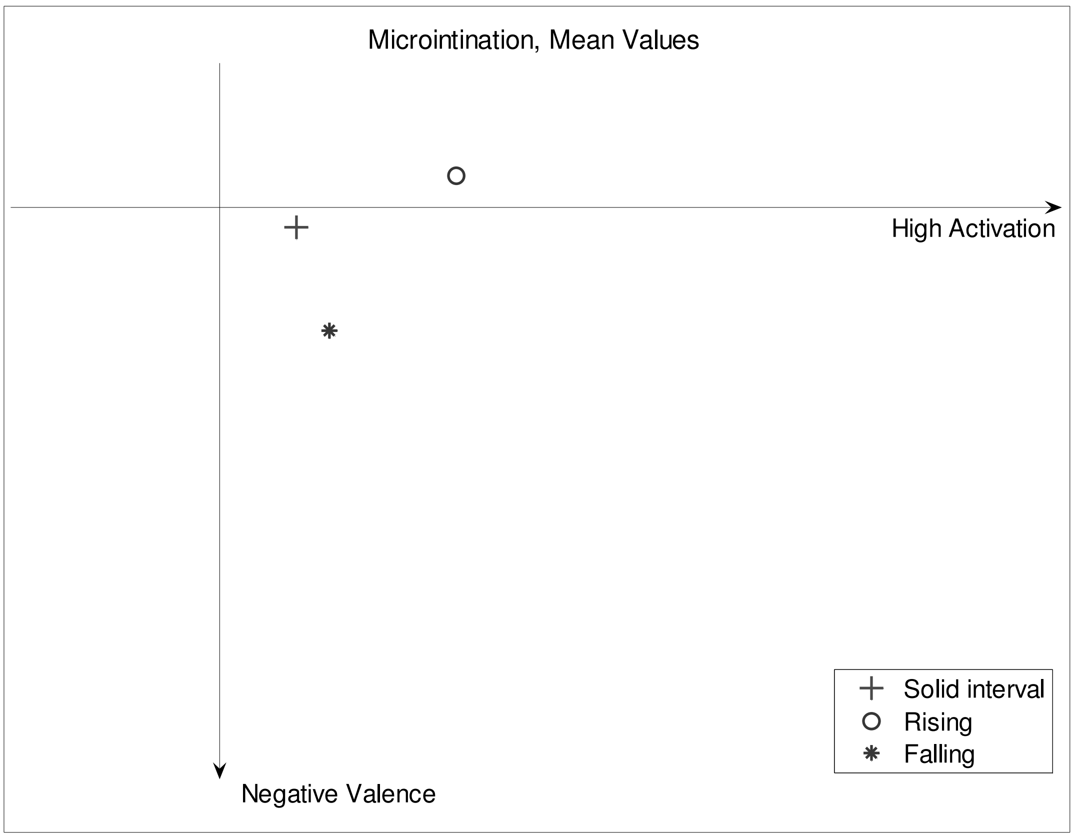

Figure 6.12: Results of microintonation, compared to solid interval.

When comparing the rising microintonation to the mean value over all solid intervals, by significance levels and through figure 6.12, a clear increase in both valence and activation appears. When the same is done with the falling microintonation, a clear decrease in valence shows. This means that a rising respectively falling microintonation brings a happier, stressing respectively sadder perception. It would furthermore be interesting to investigate a single tone rising and falling to see whether it gives me more, less or equal results as the intervals do.

Table 6.10: Significance between the data in figure 9.14.

Sounds		Sig. Pitch 6 A	V	
1	2	**0.000**	**0.025**	1 = Solid Interval
	3	0.824	**0.000**	2 = Rising Microintonation
2	3	**0.000**	**0.000**	3 = Falling Microintonation

6.4 Inconclusive Results

Ritardando, *Sound Level Variability* and *Tone Attack* were the only three acoustic parameters that were entirely inconclusive. Neither the figures nor significance levels showed any kind of tendency.

6.5 Discussion

Many of the sounds gave vague statistically significant differences. Fortunately conclusions can be made anyway. However, if the sounds that did not give any significant difference were to be designed again, a recommendation would be to try to make them less alike. This would correspond to larger steps between the levels, which probably would lead to greater difference between the answer groups and then maybe a significant difference would appear. A drawback when using larger steps however would be the loss of information between the steps. One could instead of course use the small steps if more steps were introduced in a wider range but that would mean more time, which not existed.

One example of a sound that had too similar character between the levels was *Tempo Variability*. If the sounds were made more variant, i.e. the difference between the fundamental tempo and the set of shifted tempo were larger, a larger difference would possibly appear and the figures might have been more obvious.

As for *Ritardando* that gave inconclusive results, it might have been more successful to not use a longer intro beat for all of the five levels instead of using the same number of tones (or notes). As the sounds were in the test they could evoke different perception due to the different lengths and it is very likely that the listener did not have sufficient time to respond to the shortest of the ritardando sounds due to their short duration. If the duration of the intro beat was put to e.g. four seconds for each level before the ritardando was introduced and thereby have time to adapt to the sound, it might have been possible to see only the perception of the ritardando.

There is one additional matter that should also be added to this discussion of the sounds, concerning *Mean Tempo*. It is possible that the difference between the highest mean tempi were too small to be perceived as any further activating, i.e. a logarithmically increasing tempo might have shown more influence on activation. Moreover, the lowest tempo that was used was 120 bpm, which is approximately 40 bpm faster than the average human heart beats at rest. It would in retrospect be interesting to test tempi below the human heart rate to see if those tempi have a soothing influence on the listener. The fact that relatively high tempi were used can explain the fact that all tempi tested showed a more or less activating perception of the sounds from the listener.

Now, are these acoustical parameters and musical sounds possible to use in sound design? I would have to say, -‘Yes’. When designing a sound you want to deliver information to a listener. You want the listener to understand what you want to mediate and then act from his/her conclusion of what the sound means. It would be most unfortunate if the listener got a strong emotional reaction to the sound and reacted uncontrollably. From the results of this thesis one can know the perceived emotion of a listener before the listener has heard the sound. It must be added however that no tests have been done to see if a superposition of the perceived emotions can be made by combining acoustic parameters or musical sounds.

In the questionnaire for Test 1, the test persons were asked to answer if they played an instrument or sang. This was to see if it made a difference on the result if the subjected person had any musical training or not. After dividing the subjects into one group of musically experienced and one musically inexperienced an analysis was made of the two groups to see if a difference could be noted. The analysis of the acoustic parameters showed no difference in answers between the groups. This would imply that the perceptions of the acoustic parameters are independent of musical training. However, the analysis of the intervals showed tendencies of musically experienced subjects to react stronger to the harmonic intervals, in general, compared to musically inexperienced subjects. However, they still reacted in the same way.

Nationality, which also was asked for, was unfortunately not sufficiently covered by number of subjects to analyze any closer. Nationality may influence the results because of cultural differences. The type of sounds and music the subjected person are accustomed to and has been brought up to can be important variables to know when analyzing the responses.

7 Listening Test 2 – Physiological Test

The second stage is a physiological test where the test persons were subjected to the sounds of the first listening test sounds that gave the most promising results. The physiological test is the natural continuation of Test 1. By doing a physiological test, the results from Test 1 can be verified and hopefully be improved in such a way that the results become unambiguous.

Due to lack of time only four musical sounds and acoustic parameters will be tested. The choice of sound is made from the, in my opinion, most promising and/or interesting results in Test 1. Furthermore, the sounds will be played only in pitch 6, except for when the influence of pitch is tried of course (see chapter 7.1 below).

It goes without saying that the same hypothesis as for Test 1 applies for all sounds in this test as well.

7.1 Pitch

The pitch sounds were increased in number for the physiological test. Five different pitches were tried, pitch 4,5,6,7 and 8. Otherwise they had the same character as the sounds in the first test. They were all sinusoidal, unison C-tones.

7.2 Sound Level

The results of the acoustic parameter *sound level* in Test 1 were very clear and need no improvements or widening. Therefore the same sounds are used in this physiological test.

7.3 Vibrato Amplitude and Frequency

In Test 1 the distinction between vibrato frequency and amplitude was made but not tried separately. This was done in here.
The vibrato amplitude (VA) was varied from small to high using the same vibration frequency (VF = 6 Hz) for all VA sounds.

VA 1 - 0.05		
VA 2 - 0.10		
VA 3 - 0.20		VF = 6 Hz
VA 4 - 0.40		
VA 5 - 0.80		

Analogically as the VA, the vibrato frequency will be varied from low to high, using the same vibrato amplitude (VA = 0.10) for all VF sounds.

VF 1 - 2 Hz		
VF 2 - 5 Hz		
VF 3 - 8 Hz		VA = 0.10
VF 4 - 11 Hz		
VF 5 - 14 Hz		

7.4 Harmonic Intervals

The emotional reaction of the harmonic intervals was tested with the string sounds, and the same sounds were used as in Test 1.

7.5 Combination of Musical Sound and Acoustic Parameters

To further test the hypothesis, a combination of musical sounds and acoustic parameters was tried. This is to see if a super positioning between them is possible. The designed sounds were a combination between vibrato and harmonic intervals played in two different pitches.

The chosen intervals were minor 2nd, major 2nd, minor 3rd and major 3rd. They all had a VA of 0.12 and a VF of 8 Hz.

7.6 Summary of Sounds in Physiological Test

To make it easier to get an overview of the sounds used in the physiological test, the sounds are compiled in table 7.1.

Table 7.1: Summary of the sounds used in the physiological test.

Sound type						
PITCH	Pitch 4	Pitch 5	Pitch 6	Pitch 7	Pitch 8	
SOUND LEVEL (re. level 5)	-20	-15	-10	-5	0	[dB]
VIBRATO						
Amplitude (VF = 6 Hz)	0.05	0.10	0.20	0.40	0.80	re amp. 1
Frequency (VA = 0.10)	2	5	8	11	14	[Hz]
HARMONIC INTERVALS	Unison	Min 2nd	Maj 2nd	Min 3rd	Maj 3rd	
	4th	Min 5th	Maj 5th	Min 6th	Maj 6th	
	Min 7th	Maj 7th	Octave			
COMBINATIONS	Pitch 5	Min 2nd				
		Maj 2nd		VA=0.12		
		Min 3rd		VF=8 Hz		
		Maj 3rd				
	Pitch 7	Min 2nd				
		Maj 2nd		VA=0.12		
		Min 3rd		VF=8 Hz		
		Maj 3rd				

This gives us a total number of 39 sounds in the physiological test.

7.7 Listening Test Setup

On to the subjects face, 4 and 8 mm electrodes were attached to measure the nerve signals of the Corrugator and Zygomaticus muscles. In figure 7.1 a and b one can see the electrodes being attached over the eyebrow respectively directly under the cheekbone, that is on the Corrugator respectively Zygomaticus muscles. There is also a ground electrode attached centrally on the forehead. The Currugator and Zygomaticus measurements are 83% respectively 70% coherent to valence [7]. To measure activation, the galvanic skin response (GSR) between the long and index fingers on the non-dominant hand is recorded via a pair of electrodes (see figure 7.2).

The subject was seated in a comfortable chair in a totally sound insolated room. To help the subject not to stray with his/her mind and not to close his/her eyes, the subject was asked to focus the look on a green plant located directly in front of him/her. The sounds where played to the subjects through a pair of headphones.

This test was performed together with another test, which means that the subject was exposed to a total of 3x55 sounds, where one sound was a one second loud burst of white noise. The white noise was played to hopefully have a strong reaction that we could use to normalize the other sounds to.

In order to get sufficient data from the test, twelve subjects performing the test was required. The 55 test sounds was placed in four different semi random orders in the software Presentation. One subject was exposed to first one order, and then another and finally the first order again, i.e. a total of 165 sounds. After each five second sound there was a ten second recuperation time. The total length of the test was approximately one hour including attaching the electrodes.

7.7.1 Equipment

PC 1	- DELL Dimension 2400
Operating System	- Windows XP, Home Edition
Software	- AcqKnowledge®, Version 2.8.1, BIOPAC Systems, Inc.

PC 2	- ANTEC
Operating System	- Windows XP, Professional
Software	- Presentation, Version 9.90

Pre Amplifier	- FireWire 410, M-Audio
Headphones	- STAX, Signature
Data Acquisition Unit	- MP150
Unshielded Touch Proof Electrode Adapter	- SS1A
Reusable Electrodes	- EL254S, EL258S
Adhesive disk	- ADD204, ADD208
Electrode Gel	- Signa gel, Parker Laboratories, Inc.
Cotton Swabs	- Apoliva
Skin Tonic	- ACO

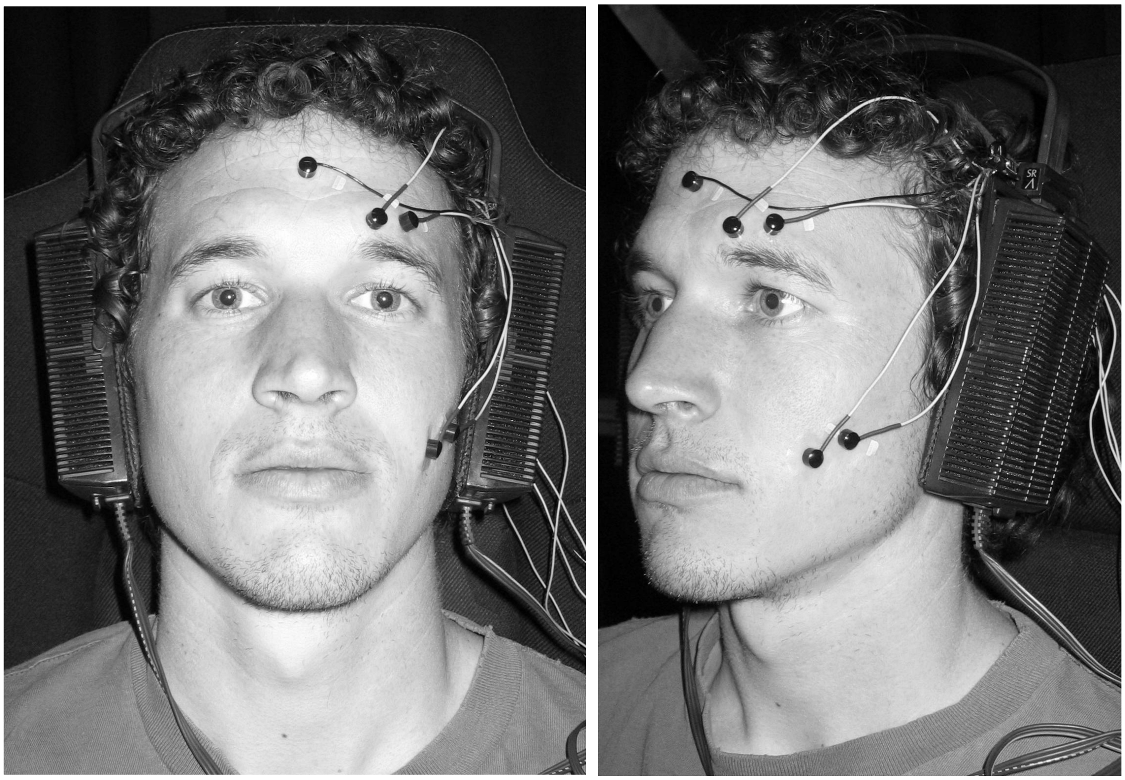

Figure 7.1 a and b: Test subject with electrodes attached.

Figure 7.2: Attachment of the GSR electrodes.

Figure 7.3: Computers running Presentation respectively AcqKnowledge®.

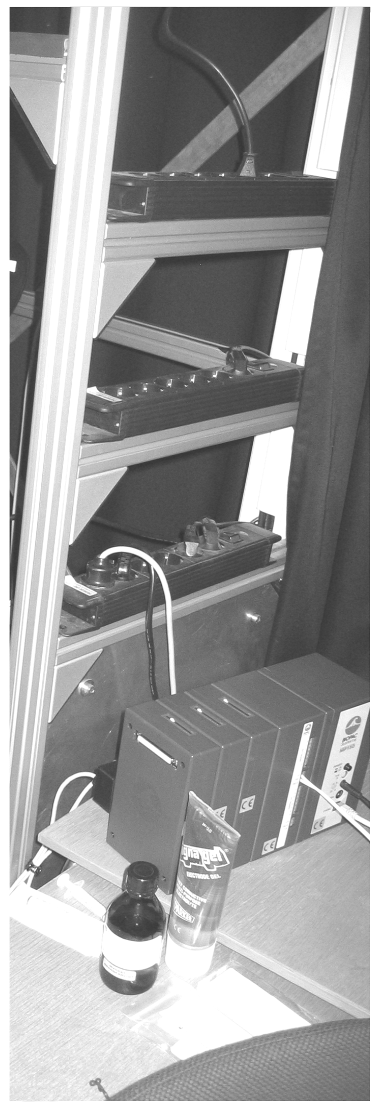

Figure 7.4: Test chair for the physiological test.

Figure 7.5: Data acquisition unit, MP150.

8 Results and Analysis – Test 2 – Physiological Test

When the test was performed the data needed to be analyzed. However, to analyze the activation response from the GSR turned out to be very time consuming and it was unfortunately time that did not exist. Therefore have only the analysis of valence been included in this thesis.

After compiling the resulting data from the measurements each person's data was normalized to the person's reaction to the one second burst of white noise. This was to make comparable data for the analysis. The mean value of the reaction to each sound was then compared in SPSS to look for significant differences between the answering groups. None was found.

For the sounds that were the exactly the same in both Test 1, where the sounds were rated, and the physiological test, Test 2, the correlation between the tests was also investigated. The correlation is shown in table 8.1 below.

Table 8.1: Valence correlation between Test 1 and Test 2.

Valence		Mean(Corr; Zyg)	Corrugator	Zygomaticus	Ratings from test 1
Mean(Corr; Zyg)	Pearson Correlation	1.000	1.000(**)	1.000(**)	-0.003
	Sig. (2-tailed)		0.000	0.000	0.991
	N	21	21	21	21
Corrugator	Pearson Correlation	1.000(**)	1.000	1.000(**)	-0.003
	Sig. (2-tailed)	0.000		0.000	0.991
	N	21	21	21	21
Zygomaticus	Pearson Correlation	1.000(**)	1.000(**)	1.000	-0.003
	Sig. (2-tailed)	0.000	0.000		0.991
	N	21	21	21	21
Ratings from test 1	Pearson Correlation	-0.003	-0.003	-0.003	1.000
	Sig. (2-tailed)	0.991	0.991	0.991	
	N	21	21	21	21
** Correlation is significant at the 0.01 level (2-tailed).					

The table above shows that there is a high probability that the ratings of, and the physiological reactions to the sounds are uncorrelated. This would mean that even if the results would show some tendencies of being effective on valence, the reaction and perception would show different influence from the same sound.

8.1 Discussion

It is clear that no conclusions can be drawn from the results that were acquired from the physiological experiment. There is a high probability that we need many more test persons to achieve any results. Furthermore, we need to analyze the results from the GSR measurement and also look deeper into the Corrugator and Zygomaticus muscle measurements. However, for now we can not say anything about the emotional reaction to these acoustic parameters and musical sounds that have been used in this thesis.

9 Summary

Test 1, where the sounds were emotionally rated on an activation respectively valence scale, shows a clear influence on emotional perception depending on high or low usage for many of the acoustic parameters.

There were however fewer results that showed to be influencing on valence, but a change in pitch was one acoustic parameter that did show just that. *Pitch* did furthermore also show influence on activation. An increase in pitch resulted in both a higher activation and more positive valence.

The results of having increasingly louder *Background Noise* showed tendencies of influencing valence perception, but no significant difference could be found in the ratings.

The most striking results were given by the parameter *Sound Level,* -the higher the sound level, the higher the activation.

The attempt to influence a person's response by using different A*rticulation* by playing a sound going from staccato to legato showed influence on activation. A *legato* articulation showed to be more activating than at *staccato* articulation, using the same tempo. However, here too we could not find a significant difference between the ratings.

Mean Tempo showed a clear tendency of an activation increase as the mean tempo was increased. Furthermore, there could also be found significant differences between the ratings for the bottom three tempi.

When the tempo was altered within the sound in the *Tempo Variability* sounds the ratings showed a slight tendency of being influencing on both valence and activation. An increase in variation between the two altering tempi would in that case lead to more positive valence and higher activation perception. Unfortunately a conclusion of this can not be made due to that they are not significantly different.

A *Vibrato* consists of two parameters, the vibrato frequency and the vibrato amplitude. The vibrato frequency showed clearly to be influencing activation perception, both from the figures and it also showed a significant difference. Vibrato frequency also showed tendencies of influencing valence but no significant difference could be found. Vibrato amplitude showed tendencies of influencing activation but not valence. However, vibrato amplitude showed no significant difference to support the activation influence.

When analyzing the perception of emotion in the *harmonic intervals*, it was found that both the sinusoidal intervals and the intervals produced by the sampled strings were in many cases perceived similarly. Over all, the string intervals were however perceived as more activating and with more negative valence than the sinusoidal intervals. Beside this difference, a relative perception to a unison tone could be found similar for both types of intervals. The fact that these two ratings showed similar results indicates that the perceived emotion of the interval can be predicted, despite no significant difference was found.

Results from ratings of *Microintonation* showed the hypothesized expectation. A rising microintonation was perceived as happier than a solid tone and a falling microintonation was perceived as sadder. Further, the rising microintonation indicated influence of being more activating too. These perception results were also statistically concurred.

Some of the tested parameters and sounds can for sure be said to be effective and others only be stated as possibly effective. A summary of the results is also shown in table 9.1, where each acoustic parameter and musical sound can be seen and how it is used to influence activation and/or valence.

Table 9.1: Summary of results of Test 1.

Affective parameters and sounds				
	Activation		**Valence**	
	Low	**High**	**Negative**	**Positive**
Pitch	Low	High	Low	High
Sound Level	Low	High		
Mean Tempo	Low	High		
Vibrato Frequence	Low	High		
Vibrato Amplitude	Low	High		
Microintonation		Rising	Falling	Rising
Possible effective parameters and sounds				
Background Noise			High	Low
Articulation	Staccato	Legato		
Tempo Variability			Low	High
Vibrato Frequence			Low	High
Harmonic Intervals	**Perception**			
CDb	High activation		Low Valence	
CD	High activation		Low Valence	
CE	Low activation		High Valence	
CGb	High activation		Low Valence	
CAb	High activation		Low Valence	
CBb	High activation		Low Valence	
CB	High activation		Low Valence	
CC	High activation		High Valence	

10 Conclusion

The aim of this thesis was to investigate if it was possible to predetermine the perception of emotion in acoustic parameters and musical sounds, and furthermore, to decide if this was possible to use in sound design.

The results show that predicting the perception of emotion in sounds is possible. They also show that they are possible to use in sound design.

11 Future work

This thesis is only scraping the surface of a very deep subject. There is much more work to be done. The possibility of combining two or more sounds and achieve the predicted perception of emotion has not been tested. Moreover, the step to emotional reaction is yet to be taken, by completing the analysis of the data from the physiological test in this thesis and furthermore expanding it.

The natural continuation of this thesis would however be to investigate the perception of emotion in sounds that combine two or more of the acoustic parameters used in this thesis.

At the moment work is being done to analyze the data gathered by physiological measurements in this thesis.

12 References

Articles and Literature

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[2] Harmonic Notes: the Structure of Music, http://yorku.ca/ghunter/Harmonic%20Notes.htm

[3] http://en.wikipedia.org/wiki/Consonance_and_dissonance

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[6] Brock, Derek & Ballas, James A. & McFarlane, Daniel C., *Encoding Urgency In Legacy Audio Alerting Systems*, Proceedings of ICAD 05-Eleventh Meeting of the International Conference on Audio Display, Limerick, Ireland, July 6-9, 2005.

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[8] Bradley, M.M. y Lang, P.J. (1994), *Measuring emotion: The self-assessment manikin and the semantic differential*, Journal of Behavioral Therapy and Experimental Psychiatry, 25, 49-59.

[9] Juslin, P. N. (2000). *Cue utilization in communication of emotion in music performance: Relating performance to perception*. Journal of Experimental Psychology: Human Perception and Performance, 26, 1797-1813.

Tools and Software

[10] MATLAB, R2006a, *TheMathWorks, Inc.*

[11] SPSS 15.0 for Windows.

APPENDIX
Listening Test 1

Most welcome to this listening test. Please read this test description thoroughly.
If there is something you do not understand, please do not hesitate to ask. If you do not ask, it could compromise the listening tests' output. Also, please do not communicate in any way with the other participants during the test. Thank you!

Introduction:
You will hear 135 different 5 second sounds played, each sound will be followed by a 10 second silence. During that silence, your task is simply to rate how inactivating/calm or activating/arousing you perceive the sound to be, and how sad or how happy you perceive the sound to be. Note the answer on the answer sheet.
After half the sounds are played, we will have a short break to clear our mind, after which we continue. The sounds shall be graded in the two ways by using a letter taken from the two figures 1 respectively 2.

Figure 1 - Activation

- "A" corresponds to very low activation, i.e. a very calm-sounding sound.
- "I" corresponds to very high activation, i.e. very arousing or stressing sound.
- "E" represents your normal activation, i.e. neither calm nor arousing sound.

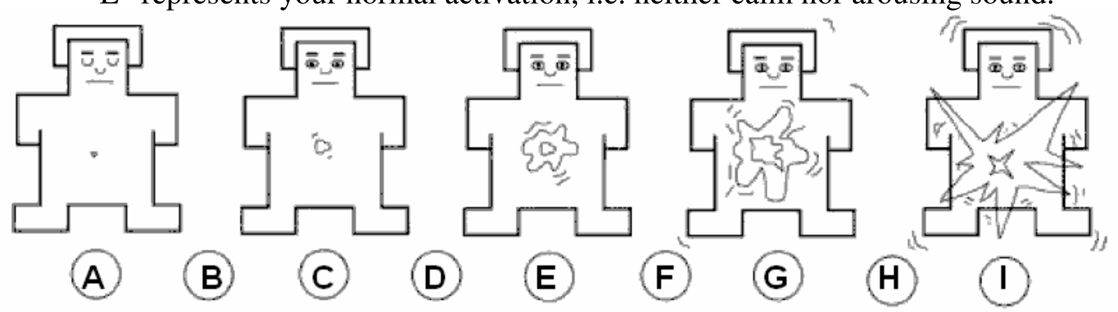

Figure 1: Inactivating/Calm and/or Activating/Arousing.

Figure 2 - Negative/sad or positive/happy

- "A" corresponds to very negative/sad.
- "I" corresponds to very positive/happy.
- "E" represents a normal state of mind, i.e. neither negative nor positive.

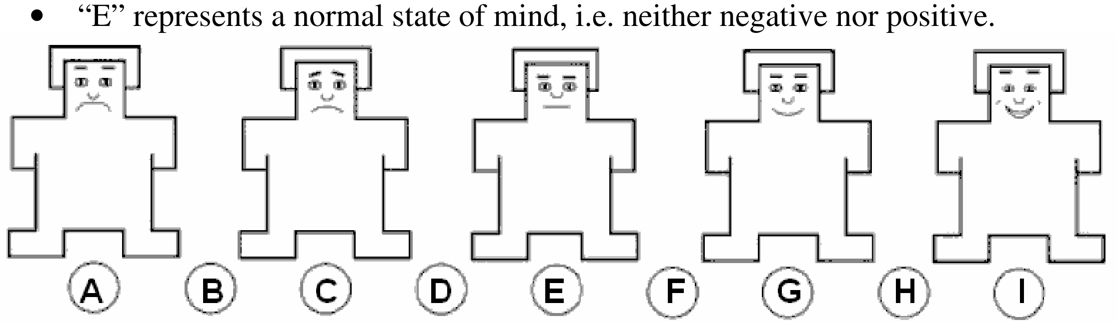

Figure 1: Negative/Sad and/or Positive/Happy.

How to rate the sounds:

The level should be chosen from the two figures 1 and 2 above, giving a letter from A through I.

Notation example:

	Activation	Happy/Sad
Sound 1	C	G
Sound 2	H	H
Sound 3	I	E
...	…	…

On the desk there should be a paper containing the same figure 1 and figure 2 as above. While you are performing the listening test you shall in turn look at each of the two figures before you answer, so that you have a fresh memory of what the emotion-figures look like.

Please answer how the sound sounds, not how you feel when you hear it!

Do NOT compare the sounds to each other. Rate each sound individually.

Wait to answer till the sound has finished playing.

When you finished reading this, please lean back on your chair so that I can see that you are ready

Listening Test

Part 1

	Activation	Happy/Sad
Sound 1		
Sound 2		
Sound 3		
Sound 4		
Sound 5		
Sound 6		
Sound 7		
Sound 8		
Sound 9		
Sound 10		
Sound 11		
Sound 12		
Sound 13		
Sound 14		
Sound 15		
Sound 16		
Sound 17		
Sound 18		
Sound 19		
Sound 20		
Sound 21		
Sound 22		
Sound 23		
Sound 24		
Sound 25		
Sound 26		
Sound 27		
Sound 28		
Sound 29		
Sound 30		
Sound 31		
Sound 32		
Sound 33		
Sound 34		
Sound 35		
Sound 36		
Sound 37		
Sound 38		
Sound 39		
Sound 40		
Sound 41		
Sound 42		
Sound 43		
Sound 44		
Sound 45		
Sound 46		
Sound 47		
Sound 48		
Sound 49		
Sound 50		

	Activation	Happy/Sad
Sound 51		
Sound 52		
Sound 53		
Sound 54		
Sound 55		
Sound 56		
Sound 57		
Sound 58		
Sound 59		
Sound 60		
Sound 61		
Sound 62		
Sound 63		
Sound 64		
Sound 65		
Sound 66		
Sound 67		
Sound 68		
Sound 69		
PAUSE		
Sound 70		
Sound 71		
Sound 72		
Sound 73		
Sound 74		
Sound 75		
Sound 76		
Sound 77		
Sound 78		
Sound 79		
Sound 80		
Sound 81		
Sound 82		
Sound 83		
Sound 84		
Sound 85		
Sound 86		
Sound 87		
Sound 88		
Sound 89		
Sound 90		
Sound 91		
Sound 92		
Sound 93		
Sound 94		
Sound 95		

	Activation	Happy/Sad
Sound 96		
Sound 97		
Sound 98		
Sound 99		
Sound 100		
Sound 101		
Sound 102		
Sound 103		
Sound 104		
Sound 105		
Sound 106		
Sound 107		
Sound 108		
Sound 109		
Sound 110		
Sound 111		
Sound 112		
Sound 113		
Sound 114		
Sound 115		
Sound 116		
Sound 117		
Sound 118		
Sound 119		
Sound 120		
Sound 121		
Sound 122		
Sound 123		
Sound 124		
Sound 125		
Sound 126		
Sound 127		
Sound 128		
Sound 129		
Sound 130		
Sound 131		
Sound 132		
Sound 133		
Sound 134		
Sound 135		

Please turn the page.

Thank you very much for participating in my listening test. Now if you would pleas take a minute or two to fill in this questionnaire.

When you are finished, please leave all papers on the desk, and you are free to leave.

Thank you.

Questionnaire:

Gender? M ☐ F ☐

Age? ____________ *years old*

Nationality: ____

Are you hearing impaired? Yes ☐ No ☐
If yes:
*What kind of impairment?*____

Are you musically experienced? I.e. do you play any instrument or sing, etc? Yes ☐ No ☐
If yes:
What instrument? ____
How long have you been playing it? _____________________________
How many hours per week do you play? ________________________

What kind of music do you listen to? (Please choose one or more from below)

Classical	Hip-Hop	Rock	Jazz	other:_____________________
Electronic	Pop	Soul	Reggae	other:_____________________
Hard Rock	Punk	World	Indie	other:_____________________

What are your three favorite bands/artists? (Please state band name – genre)

BAND NAME GENRE

1. ____-________________________________
2. ____-________________________________
3. ____-________________________________

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