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Perception of whole body vibration

Masters Thesis in the Masters programme in Sound and Vibration

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Picture of the used vibration floor. The floor will be further described in Part II Chapter 2 "The vibration floor".
The picture was taken at the "Day of Science 2010" at Carl von Ossietzky Universitt Oldenburg.

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Abstract

There are many everyday situations where the human body is exposed to vibration, for example in vehicles and buildings.

People who are exposed to whole body vibration, use complex descriptions for the perception of vibration. The perception is described differently for different frequency ranges, for different amplitudes and for different kind of signals.

The first part of this thesis is about the descriptions of the different sensations of sinusoidal whole body vibrations, depending on the excitation frequency. There were found different percepted frequency regions and describing items for the perceptions.

The second topic in this thesis deals with the perception of modulation. The differences between the perception of coherent and incoherent fluctuations in level chould be analysed. The filters for the frequency selectivity in vertical whole body vibration detection shown in other studies could be reproduced, but the expected differences for coherent and incoherent signals could not be established.

Keywords: Vibration Perception, Whole Body Vibration, CDD, Psychoacoustics

Contents

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Part I.

Main Introduction

There are many everyday situations where the human body is exposed to vibration, for example in vehicles and buildings. For vibrations in buildings, examples are the vibrations due to railways close to the building or due to a big building site nearby.

There are several investigations on comfort and health risks of vibration (for example [16], [13], [2], [23] and [21]) but there is not much known about the perception of vibration.

People who are exposed to whole body vibration, use complex descriptions for the perception of vibration. The perception is described differently for different frequency ranges, for different amplitudes and for different kind of signals.

There seem to be different effects influencing the perception of vibration, like if the signal is sinusoidal or a narrow band or a broadband signal, how the modulations are, if the frequency is high or low and if the amplitude is high or low.

There are many words which can be used to describe the different perceptions. The goal of the first part of this thesis is to describe the different sensations of sinusoidal whole body vibrations, depending on the excitation frequency, since the effect of different frequencies seem to have a strong influence on the perception.

The following questions are addressed in part 1: Are there words describing the different perceptions which can be generalised? How far does the perception change over the frequency range. Can the sensations be categorised in different groups of perception or are they just slightly changing? To answer those questions three experiments were performed.

The second topic in this thesis deals with other points of vibration perception. Bellmann and Ewert found that filters can be identified for the frequency selectivity in vertical whole body vibration detection.

Following these results, the point of interest in this part of this thesis was to find out a bit more about the perception of modulation, and if there are differences in the perception of coherent or incoherent fluctuations in level.

Part II.

Perception of vertical sinusoidal whole body vibration

1. Introduction

Listening to people who are exposed to whole body vibration, it is noticeable that the perception of vibration is described differently for different frequency regions.

A lot of different words can be used to describe the different perceptions. The goal of this study is to describe the different perceptions of whole body vibrations, depending on the excitation frequency. To achieve this three experiments were performed.

All experiments were done on an existing vibration floor, developed by Bellmann in [3].

In the first experiment definitions for the observed perceptions were collected in a free verbalisation experiment. In the second experiment the relevance for these definitions was evaluated for a subset of frequencies.

The third experiment was based on the first two experiments. The results about frequency ranges and definitions which describe the different perceptions were used to create an experiment with two different semantic differentials. The first one to have a rough analysis for a bigger amount of words and the second one for a more detailed analysis for some descriptors which seem to fit best.

2. The Vibration Floor

The vibration floor is a movable platform for exposing probands to whole body vibrations with a minimum of sound emission. The whole setup can be seen in figure 2.1.

The platform has been developed by M. Bellmann in his Doctoral Thesis [3] and improved by M. Hoelling in his Diploma Thesis [14].

To minimize the emission of sound the platform is made out of a metal grid. The grid is moved by a shaker (S1) in z-direction. The directions are according to the ISO standard [1] for seated probands. For the probands a rigid chair without armrests is mounted on the grid. With an accelometer (A) below the chair the excitational accelerations can be measured.
There is a second shaker (S2) mounted to the platform for the excitation in y-direction, which is not used for the experiments in this thesis. Following the results of [3] and [14] the z-axis it the main direction for vibration. So the focus in the following experiment is on the perception in the direction of the z-axis. It is assumed that the unused part of the set-up does not influence the results of the following measurements. The excitation signals were created in Matlab and were transmitted from the computer via a DA-converter and an amplifier to the shaker.

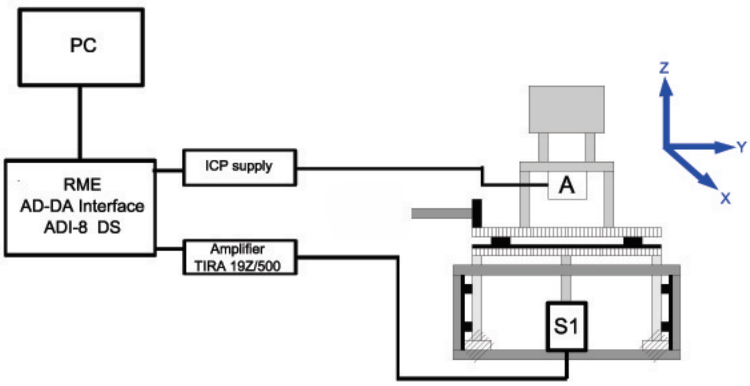

Figure 2.1.: Drawing of the Vibration-floor set-up: Probands seated on ridged chair mounted on a metal grid moved by shaker (S1) , accelometer (A)

Figure 2.2.: Side view of the Vibration-floor with a seated proband

The platform can play-back vibrations from 4 Hz up to 90 Hz. Around 60 Hz it begins to emit sound, since there is the first grid resonance. The transfer function for an excitation with random noise from 2 Hz to 120 Hz for the empty platform and with a medium height and weight proband (BMI: 21.7, height: 182 cm, weight: 72 kg) can be seen in figure 2.4.

Figure 2.3 shows the measured acceleration frequency responses of the platform to an excitation with a broadband noise from 2 Hz to 120 Hz in z-direction. The different excitation axes and the input signal (Ref) are marked by different colors.

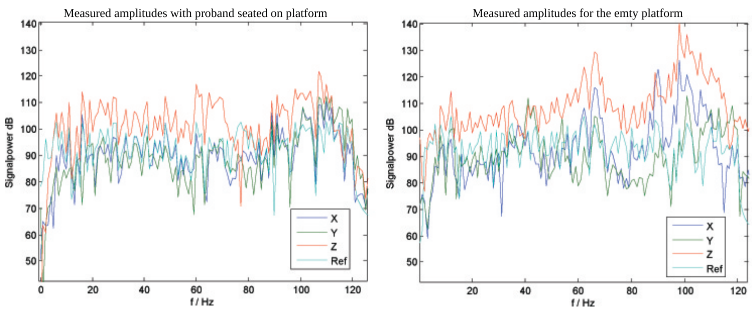

Figure 2.3.: Measured acceleration amplitudes on the platform for an excitation with broadband noise from 2 Hz to 120 Hz in z-direction; in the left plot are the results for the platform with a proband seated on it, in the right plot is the same measurement done for the empty platform

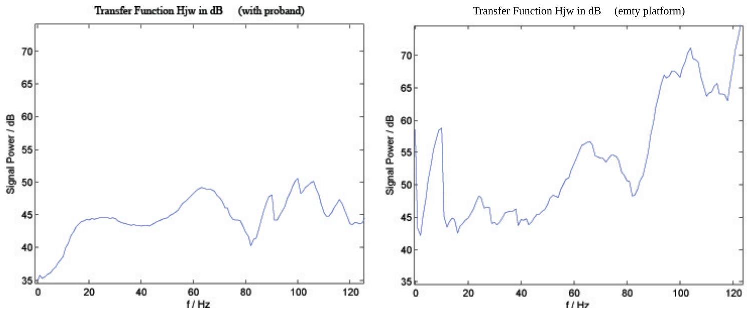

Figure 2.4.: Measured transfer function of the platform for an excitation with broadband noise from 2 Hz to 120 Hz in z-direction; in the left plot are the results for the platform with a proband seated on it, in the right plot is the same measurement done for the empty platform

The platform can handle amplitudes up to 120 dB(ISO), but with such high amplitudes there are clear sound emissions. Up to 110 dB(ISO) the platform is moving quietly.

3. Analysis Methods

3.1. Factor Analysis

A factor analysis can be used to reduce and sort a large amount of data. It is a method to find similarities between the variables and use these similarities to group the variables into a smaller amount of factors as described in [8] and [11].

To archive this goal, the factor analysis uses a correlation matrix to compare if variables have similarities or not. A group of similar variables build a factor. Depending on how well the factor describes the variable, the variables have different loadings on the factor. The similarities between the variables in one factor and the difference of these to the variables in other factors can be used to describe the "meaning" of a factor.

The higher the correlation of the variables is, the less factors are needed. In the present study, the factor analysis has been done with SPSS like the instructions in [6] show and a varimax rotation has been used.

The factors are sorted and numbered by the variance they explain.

Variance In a factor analysis the variance of a factor explains the amount of variables that could be described by this factor. There are different ways to calculate the variance: the total variance and the percentage variance.

The total variance is compared to the total number of variables. For example if there are four variables, an absolute variance of 2 would mean that half of the variables could be explained by the factor, while it means that only a quarter of the variables could be explained in the case of a total of eight variables. So this value is good to decide how many of the factors are still meaningful (absolute variance bigger than 1) but it can not be used to compare the results of different factor analyses.

For this purpose it is possible to use the percentage variance were 100 % variance means that all variables could be explained, and 5 % means that half of the variables could be explained by the factor.

Varimax rotation The varimax rotation is an orthogonal rotation method, which tries to reach a minimum correlation between the different factors and a high variance for each factor.

The first factor explains the highest variance.

The next factor should be as independent as possible from the first one (preferable orthogonal to it) and has a maximum variance of the squared loadings of the rest of the variables. The maximum number of factors which can be found is the total number of variables.

The total absolute variance of the factors is equal to the amount of variables. Factors with an absolute variance smaller than one can not help to clarify the data since it is smaller than the variance of a single variable.

Screeplot There are different methods to find out how many of the calculated factors are meaningful. One test is the Screeplot.

The Screeplot is an Eigenvalue plot which shows the Eigenvalues of the factors over the order of the factor.

Beginning with the lowest order one can see there is a group of factors with similar size. They are just slowly and nearly linear growing. At some point there is a break and afterwards the slope is much steeper and no longer linear. One can range all factors before the break as meaningful and the rest as meaningless factors. More detailed descriptions can be found in [8] page 544 or pages 385f. in [6]

Kaiser-Meyer-Olkin-Criterion The Kaiser-Meyer-Olkin-Criterion (KMO) is a value to analyse if a correlation matrix can be used for a factor analysis. The value lies between 0 and 1. As long as it is higher than 0.5 it is reasonable to use a factor analysis.

3.2. Semantic differential

The semantic differential has been developed by Osgood in 1957 (see in [11], pages 185f.). In Germany it became popular as "Polarittsprofil" by Hofsttter in the following years.

It has been developed as a scaling instrument for the measurement of meaning (further explained in [19]). The judgement is done by metaphoric relation or an emotional relation to the object and not on "the matter of fact".

The semantic differential consists of several semantic scales. Each scale is defined by a polar pair of adjectives. Examples for these polar adjectives could be "smooth-rough" or "loud-silent".

It is prefered to use polar pairs of adjectives, but there is also the possbility to create an artificial polar scale by using one adjective and a scale for example from "agree" to "dissagree".

The space of a semantic scale is assumed to be a straight line and can be divided in equal distant steps. The most popular way is to use a scale in seven steps, as done in two of the following experiments.

For the study of the frequency dependence of the perceptions of whole body vibrations it is nessecary to find attributes describing vibration perception. These can than be further classified by the use of a semantic differential.

For hearing acoustics, semantic differentials are often used to characterize sounds. There are different kind of semantic differentials known for this.

In the car industry, semantic differentials are, for example, used to analyse the sound and vibration impression of cars in different driving situations.

4. Free verbalisation

4.1. Free verbalisation experiment

To find definitions for the perceived phenomena, 20 (untrained) probands were exposed to a continuous sinusoidal sweep from 1 Hz - 50 Hz of two minute duration, and asked to describe their perception.

4.1.1. Aim

Vibration can be perceived differently depending on frequency and the kind of the signal. This study focuses on the perception of different frequencies for sinusoidal vertical whole body vibrations with constant amplitude.

To get an idea if the perception changes over frequency and how the perceptions can be described, a free verbalisation experiment has been designed.

4.1.2. Method

Task The task for the proband in this experiment was to mention words which describe their actual perception of the signal, and indicate when this perception starts and stops or changes. The description was noted by the investigator in a 1 Hz grid. An example answer protocol can bee seen in the appendix in figure .1

Signal The signal was a continuous sinusoidal sweep from 1 Hz to 50 Hz, generated with a HP 3321A function generator. The duration of one sweep was two minutes. The amplitude was adjusted in a way that the proband felt the oscillation as good observable, what was asked in the beginning of the experiment.

Probands 17 probands participated in the experiment, 3 female and 14 male. All were native German speakers, so all the descriptions were collected in German. The average age was 31 years, with a maximum of 63 years and a minimum of 24 years. The average height was 181.4 cm, with a maximum of 196 cm and a minimum of 161 cm. The average weight was 83.3 kg, with a maximum of 115 kg and a minimum of 60.5 kg.

Performance At the beginning the probands got introduced to the signal. One run of the sweep has been played for them to get an impression of the whole signals. Then the sweep was repeated three times while the investigator noted the descriptions. A new page has been used for every repetition.

4.1.3. Results

All the mentioned words and their direct translations to English can be seen in figure 4.1. The translation is only descriptive.

German	English
aufundab	up and down
brummen	humming
Durchschaukeln	rocking through
Durchschütteln	shaking through
Flugzeugstart	start of an airplane
holpern	jolt
Holperpiste	bumpy road
jede Schwingung	every oscillation
Kontaktflächen	contact area
Kopfsteinpflaster	cobblestone
Kribbeln	tingle
rau	rough
rütteln	jiggle
Rüttelplatte	vibrating plate
schaukeln	rocking
Schiffsdiesel	ship diesel engine
schütteln	shaking
Schwanken	oscillate
Schwingen	swing
Schwingkribbeln	swing- tingle
Seegang	motion of the sea
surren	buzz
Trecker	tractor
unruhig	fluttering
Vibration	vibration
wabbeln	wobbleing
wackeln	Joggle

Table 4.1.: Words mentioned by the probands while they were exposed to the sinusoidal sweep and the direct descriptive translation to English.

To see if the used words describe different frequency ranges and how often the words were used the mentioned words were plotted over frequency and over the amount they are mentioned in figure 4.1.

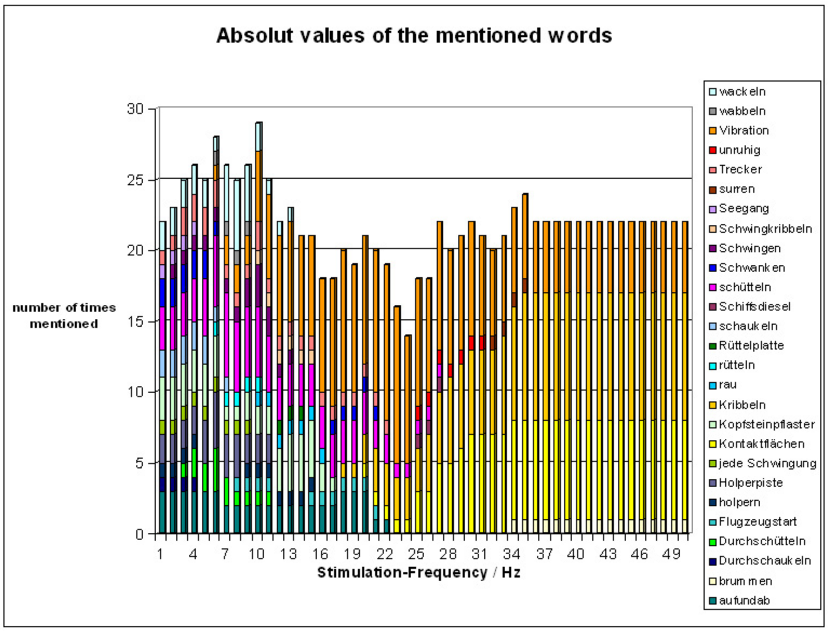

Figure 4.1.: Perception of oscillations with seated probands: The number of words mentioned by the probands is shown over the oscillation frequency. The definitions are coming from probands (N=20) which were excited with a sinusoidal sweep from 1 Hz up to 50 Hz.

In figure 4.1 it can be seen that a lot of definitions fit quite clearly to special frequency regions. Only some words like for example "vibrieren" are used over almost the whole frequency range(beginning with 6 Hz uo to the highest asked frequencies).

Noticeable is the high number of definitions for the low frequency region. For high frequencies there were just some definitions mentioned (brummen, kribbeln and Kontaktflchen), but from most of the probands. In the excitation frequency region between 22 Hz and 25 Hz only a few terms were used at all. Most probands mentioned "vibrieren", for some it was still "schtteln" or "auf und ab" and for some it was already "Kontaktflchen" or "kribbeln"

A (varimax-rotated) factor analysis over the frequency and over the mentioned words in the sweep experiment has been done. The criteria for the amount of factors taken into account was that the absolute variance has to be higher than one. The results are shown in table 4.2. It can be seen, that different frequency regions could be described by different factors as expected after the analysis of figure 4.1.

Six factors with different frequency groups are found.

For most of the factors the highest loadings for the frequencies are lying in the middle of the frequency range of the factor. To the sides of the factors the loadings are dropping.

Frequenzen	Faktoren					
	1	2	3	4	5	6
40Hz	0,949	0,068	0,014	-0,110	-0,101	-0,166
36Hz	0,949	0,068	0,014	-0,110	-0,101	-0,166
38Hz	0,949	0,068	0,014	-0,110	-0,101	-0,166
37Hz	0,949	0,068	0,014	-0,110	-0,101	-0,166
39Hz	0,949	0,068	0,014	-0,110	-0,101	-0,166
35Hz	0,933	0,101	0,038	-0,091	-0,138	-0,179
34Hz	0,923	0,146	0,036	-0,074	-0,125	-0,162
33Hz	0,889	0,249	0,028	-0,040	-0,100	-0,130
32Hz	0,866	0,305	0,024	-0,023	-0,088	-0,114
31Hz	0,796	0,478	-0,027	-0,035	-0,101	-0,123
30Hz	0,762	0,536	-0,003	0,010	-0,113	-0,130
29Hz	0,724	0,583	0,001	0,022	-0,105	-0,121
28Hz	0,684	0,623	0,010	0,032	-0,097	-0,112
25Hz	0,241	0,844	0,270	0,009	-0,116	-0,153
26Hz	0,328	0,830	0,184	0,048	-0,111	-0,136
24Hz	0,222	0,762	0,440	0,045	-0,055	-0,110
27Hz	0,514	0,740	0,096	0,024	-0,139	-0,156
23Hz	0,174	0,685	0,561	0,048	-0,029	-0,150
19Hz	-0,033	0,115	0,898	0,309	-0,011	-0,055
20Hz	0,042	0,209	0,896	0,252	-0,012	-0,063
18Hz	-0,046	0,091	0,877	0,362	-0,037	-0,073
21Hz	0,050	0,445	0,803	0,064	-0,071	-0,168
17Hz	-0,048	0,036	0,735	0,530	-0,047	-0,040
22Hz	0,125	0,578	0,683	0,092	-0,028	-0,134
13Hz	-0,091	0,044	0,169	0,937	-0,034	-0,033
12Hz	-0,072	0,054	0,194	0,931	-0,002	-0,013
14Hz	-0,068	0,044	0,230	0,914	-0,059	-0,050
15Hz	-0,062	0,014	0,316	0,881	-0,052	-0,048
11Hz	-0,130	0,005	0,084	0,795	0,297	-0,085
16Hz	-0,008	0,014	0,556	0,719	-0,002	0,030
10Hz	-0,230	-0,035	-0,010	0,670	0,478	-0,107
8Hz	-0,192	-0,110	-0,023	0,044	0,920	0,078
9Hz	-0,222	-0,110	-0,108	0,179	0,870	-0,037
7Hz	-0,179	-0,110	0,011	-0,010	0,822	0,308
3Hz	-0,228	-0,119	-0,088	-0,052	0,022	0,933
4Hz	-0,240	-0,123	-0,093	-0,071	0,024	0,929
2Hz	0,202	-0,112	-0,074	-0,020	0,056	0,921
1Hz	-0,196	-0,113	-0,066	-0,009	0,013	0,910
5Hz	-0,223	-0,122	-0,072	-0,082	0,187	0,843
6Hz	-0,219	-0,106	-0,070	-0,104	0,557	0,608
%Varianzen	27,522	12,941	13,11	14,213	7,891	12,668

Table 4.2.: Results of the factor analysis (varimax rotated) over the frequencies from 1 Hz to 40 Hz for the mentioned definitions from the 20 probands. The intensive colors illustrate the classification of the frequencies in the different factors. The softer colors illustrate a loading in an (also in frequency region) neighbored factor. In the lowest line the variance contingent which is clarified by the factor is shown.

The lowest loadings have those frequencies who are neighbored to frequencies in the next factor.

For example in the second factor the highest loading has 25 Hz with 0.844. 26 Hz (0.830) and 24 Hz (0.762) are a bit lower, and the lowest ones are 27 Hz with 0.740 and 23 Hz with 0.685.

These frequencies have also a quite high loading in the neighbouring factor. An example are 22 Hz and 23 Hz. They are falling into different factors. 22 Hz has the highest loading with 0.683 on the third factor, but also a loading of 0.578 on the second factor while 23 Hz has the highest loading of 0.685 on the second factor and a loading of 0.561 on the third factor. This slight overlap is clarified in the table by the use of softer colors.

4.1.4. Discussion

One can see in figure 4.1 that the descriptors are used for different frequency regions by the probands. There seem to be six different frequency regions of perception, as the factors in table 4.2 show.

Prelimanary tests with frequencies up to 60 Hz indicate that there are no further changes in perception.

It is interesting that the different groups are neither equidistant on a linear frequency scale nor on a logarithmic scale.

It might be interesting to see if these frequency regions can be characterised by the descriptors. For this an experiment with two different kind of semantic differentials has been designed in chapter “Analysing perceptual dimensions with a semantic differential”.

4.2. Verbal Protocol Analysis

There can be found different ways to analyse results of free verbalisation experiments in the literature. The early approaches have rough classification: [22] uses three groups and [19] and Namba and Kuwano in for example [17] three main factors. The most complex analysis is the verbal protocol analysis by Nosulenko who uses several steps to classify the attributes. This method is explained in [20]. Another difference between the approaches is that Wright and Nosulenko work with a linguistic analysis of the words, while Osgood and Namba and Kuwano start with a factor analysis and searched for the meaning of the different factors.

Wright analysed in [22] telephone-like sounds, and divided the vocabulary into three groups: onomatopoeic terms, illustrations and physical characteristics of the sound.

For onomatopoeic terms she gives examples like "bleep", "buzz" or "pop". These category is not easy to use for vibration, since it describes a sound impression and not a feeling. But some mentioned words in this experiment can however be interpreted that way, since they are polimodal, like "surren (buzz)" and "wabbeln (wobbling)".

For the illustrations she mentioned for example "whistle". In the presented experiment the words "Flugzeugstart", "Holperpiste", "Kopfsteinpflaster", "Rttelplatte", "Schiffsdiesel", "Seegang" and "Trecker" are clearly illustrative.

For physical characteristics Wright mentioned words like "high/low"or "long/short". In this experiment those characteristics were not mentioned since the signal was continuous and the amplitude was kept constant.

Osgood talkes in his book [19] about three main factors he found in his analysis. The first one is the evaluative factor which means jugdements like good - bad, ect. The second one the potency factor which concerns for example power or weight. The third factor one is the activity factor which is described by expressions like excitement, agitation and quickness. All of them were found by him in completely different kinds of experiments.

Namba and Kuwano applied the Factors found by Osgood on acoustic signals and described the results in different papers (for example in [17]). They also found three factors: The powerful factor, the pleasant factor and a third factor described as metallic factor.

The powerful factor is described by items like "loud", "strong", "quiet", or "soft". The pleasant factor is described by items like "pleasant", "unpleasant", "beautiful" or "ugly". The metallic factor is characterised by words like "shrill", "calm", "deep" and "metallic".

For this vibration experiment most of the mentioned words would fit into the metallic factor.

Since there was no information asked about pleasantness, there are not much items fitting to this factor.

There was no information about potency or power asked , so there were no items mentioned belonging to the powerful factor. Still one could interpret that words like "kribbeln" or "schtteln" submit an information about power but they would also fit into the metallic factor.

A newer approach is the verbal protocol analysis by Nosulenko et all, for example described in [20]. They designed a complex structure to analyse the answers of a free verbalisation experiment by the logical sense, the stimulus relatedness and the semantic aspects.

The analysis of the logical sense is an analysis of similarities or differences in comparisons. Since in the experiment of this study only single word descriptions were asked and no comparisons, this part is not used here.

The analysis about stimulus relatedness first divides into global and specific aspects. In this experiment only specific aspects were asked. Nosulenko further divides the specific aspects into spatial, temporal, spectral and intensive aspects.

With spatial characteristics he describes how much space the sound occupies, or its localisation in space. For vibration it could mean localisation of the perception in the body or outside, like " Kontaktflchen" or words like "auf und ab" which clearly describe a perception with the whole body.

With temporal characteristics, words like "schwingen", "wackeln", "unruhig" and "rtteln" could be described, since they describe a perception which depends on temporal aspects.

Spectral characteristics could be words like "kribbeln" or "brummen" which clearly describe either high or low frequencies. The spectral aspect was also the aim of the experiment.

There were no intensity characteristics asked in this experiment. The intensity was kept constant, but still words like for example "summen" seem to have a lower intensity like for example "rtteln".

The semantic aspect is divided into features and holistic meaningful entities.

The features are divided into descriptive and attitudinal features in the next step. There were no attitudinal features mentioned in this experiment. The descriptive features are further divided into unimodal or polymodal. In Nosulenkos work this means if the feature could only be used to describe auditory phenomena or if they can also be used to describe other sensory modalities. In this experiment examples for unimodal descriptive features are "kribbeln" or "schaukeln". Examples for polymodal descriptive features are "unruhig", "brummen", or "surren".

Nosulenko further divides the holistic meaningful entities into related or unrelated to sound. In this case it would mean related or unrelated to vibration. Both are further divided into real objects or abstract concepts and distinguished between natural and artificial objects.

In this experiment "Seegang" would be an example for a holistic meaningful entity which is related to vibration and real and natural, while "Rttelplatte" is an artificial real object which is related to vibration. "Kopfsteinpflaster" is unrelated to vibration and a real object. Also "Trecker" is unrelated to vibration but an artificial real object.

There are different approaches to adjust it for different tasks and topics, as J. Berg did in [5], who uses only a small part of the verbal protokoll analysis. He only distinguishes between descriptive and attitudinal, and further the descriptive between unimodal or polymodal, and the attitudinal between emotional and evaluative, respectively between artificial and natural.

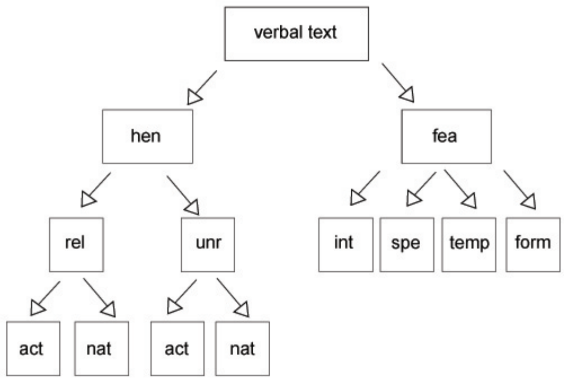

Figure 4.2.: Scheme of the verbal data analysis done with the results of the free verbalisation experiment according to the scheme of Nosulenko. hen: holistic meaningful entities; fea: features; rel: related to vibration; unr: unrelated to vibration; act: artificial; nat: natural; int: intensity characteristics; spec: spectral characteristics; temp: temporal characteristics; form: form of the motion

Based on the mentioned ideas an analysis fitting to this kind of vibration experiment can be designed. In figure 4.2 one can see a scheme of the verbal data analysis done with the words collected in the free verbalisation experiment. The mentioned words are first divided into features or holistic meaningful entities.

The features are further characterised by how they describe intensity, spectral, or temporal characteristics or how they describe a form of the motion (if the motion seems to be for example sinusoidal, harmonic or angular).

The holistic meaningful entities are further divided into related or unrelated to vibration and whether they are natural or artificial.

A list of all words categorised with this sheme can be found in the table 4.3.

Auf und ab	fea			temp	form
brummen	fea	int	spec		form
Durchschaukeln	fea			temp	
Durchschütteln	fea	int		temp	
holpern	fea			temp	form
jede Schwingung	fea			temp	form
Kontaktflächen	fea	int			
Kribbeln	fea	int	spec		
rau	fea				
rütteln	fea	int		temp	
schaukeln	fea			temp	form
schütteln	fea	int		temp	
Schwanken	fea		spec	temp	
Schwingen	fea				form
Schwingkribbeln	fea				
surren	fea	int	spec		
unruhig	fea			temp	
Vibration	fea				
wabbeln	fea			temp	
wackeln	fea	int		temp	form
Rüttelplatte	hen	rel	act		
Holperpiste	hen	rel	nat		
Seegang	hen	rel	nat		
Flugzeugstart	hen	unr	act		
Kopfsteinpflaster	hen	unr	act		
Schiffsdiesel	hen	unr	act		
Trecker	hen	unr	act		

Table 4.3.: Mentioned words in the free verbalisation experiment, with the classification after the verbal protocol analysis in Fig. 4.2. The words are first divided into features and holistic meaningful entities. The features can be further characterised by describing intensity, spectral or temporal characteristics, or describing the form of the signal. The holistic meaningful entities can be divided in related to vibration or not, and then into natural or artificial.

5. Preexperiment about perception dimensions for sinusoidal oscillation excitation

5.1. Aim

To investigate if the descriptions mentioned (by the first 5 probands) in the free verbalisation experiment can be used to describe different frequencies a semantic differential has been designed. This experiment has been started this early to test if the used procedure leads to reasonable results.

5.2. Method

For the oscillation-exciting frequencies, dimensions descibing the evoked perceptions, mentioned in the free verbalisation experiment, were analysed.
These dimensions were used in a semantic differential to measure the occurrence of the perception with 15 probands. On a scale with seven steps from agree to disagree the probands should mark how well the perceptions fit to the given definitions.

The used words and their translation to English can be found in the appendix in figure .2.

Signals Since in this early state of the investigation there were no results about frequency grouping availible, as sinusoidal signals the one third octave band middle frequencies 8 Hz, 16 Hz, 24 Hz and 40 Hz were chosen.

The signals were generated in Matlab and had half a second fade in and fade out in form of a half hanning window.

The amplitude has been adjusted for every proband at the beginning of the experiment in a way that he/she felt the signals as good observable which was at about 100 dB(ISO).

The excitation signals had a duration of 10 seconds.

Participants 11 probands participated in the experiment, 3 female and 8 male. They were all native German speakers, so all the descriptions were in German.

The average age was 29.8 years, with a maximum of 41 years and a minimum of 24 years, the average hight was 181.3 cm, with a maximum of 196 cm and a minimum of 161 cm and the average weight was 84.4 kg, with a maximum of 115 kg and a minimum of 60.5 kg.

All of the probands participated also in the first experiment.

Performance The experiment has been done once for every frequency and every proband. At the beginning the probands had been made familiar with the signals by playing every frequency one time for them.

The experiment was done directly after the first experiment.

5.3. Results

In figure 5.1 the ratings of the semantic differential for the four frequencies averaged over all probands can be seen. In the figure the scale goes from 1 (meaning that the probands agree that the description fits to the perception) to 7 (meaning that the probands disagree).

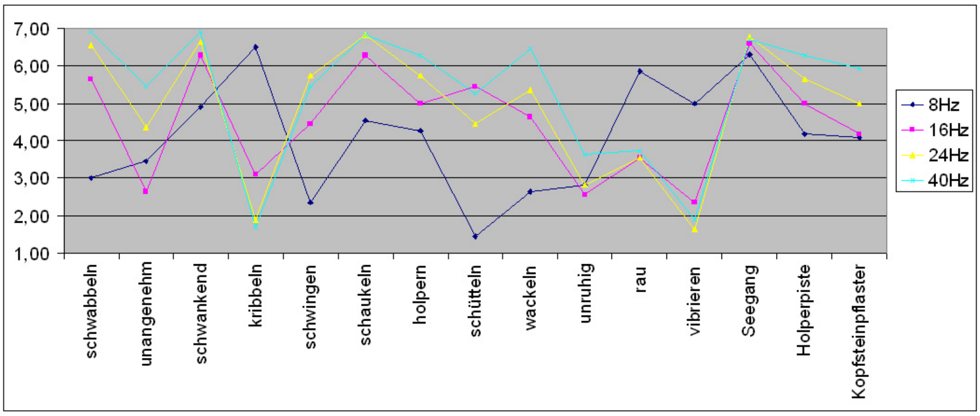

Figure 5.1.: Mean values of the answers of the semantic differential for the four frequencies over the 15 probands. 7 means disagree, while 1 means agree.

There can be seen that the characteristics for the different frequencies differ from each other. Specially for 8 Hz where the characteristic differs significantly from the others. Whereas 24 Hz and 40 Hz have a very similar characteristic.

The ratings of the probands were analysed with a (varimax-rotated) factor analysis as can be seen in table 5.1.

Three factors can be found with the factor analysis.

	Component		
	1	2	3
schwanken	0,79	-0,03	0,01
kribbeln	-0,74	-0,35	0,26
schwabbeln	0,73	0,27	0,01
wackeln	0,71	0,31	0,00
vibrieren	-0,69	-0,07	0,35
schaukeln	0,66	0,31	0,10
unangenehm	0,44	0,14	0,21
holpern	0,21	0,73	0,07
Kopfsteinpflaster	0,04	0,70	-0,16
schütteln	0,47	0,66	0,09
Holperpiste	0,20	0,64	0,14
schwingen	0,53	0,64	0,01
unruhig	0,17	-0,03	0,85
rau	-0,30	-0,48	0,62
Seegang	-0,07	0,32	0,55
% Variance	28,77	20,19	11,38

Table 5.1.: Factor loadings of the items of the semantic differential (15 probands). In the lowest line the variance contingent which is clarified by the factor is shown.

In the *first* factor are definitions which describe more *steady or harmonic movements*. The definitions with *positive* sign describe the perception for *low frequencies*, those with *negative* sign the ones for *high frequencies*.

In the *second* factor is a group of definitions which is used for *low frequencies* and characterises more *unsteady movements*, with exception of "schwingen" which would be assumed to be harmonic.

On the *third* factor the words "unruhig" (unsteady) and "rau" (rough) which show no strong frequency dependence are loading.

The frequency dependent dominance of the factors is shown in figure 5.2. There the mean values over the definitions belonging to one group and over all probands are plotted over the four frequencies. The first factor is divided into two groups according to the algebraic sign.

For the first factor the characteristic for the definitions "kribbeln" and "vibrieren " is counterwice to the characteristic of "schaukeln", "schwabbeln" and "wabbeln" . The definitions of the second factor describe higher frequencies better than the ones from the first factor with positive sign.

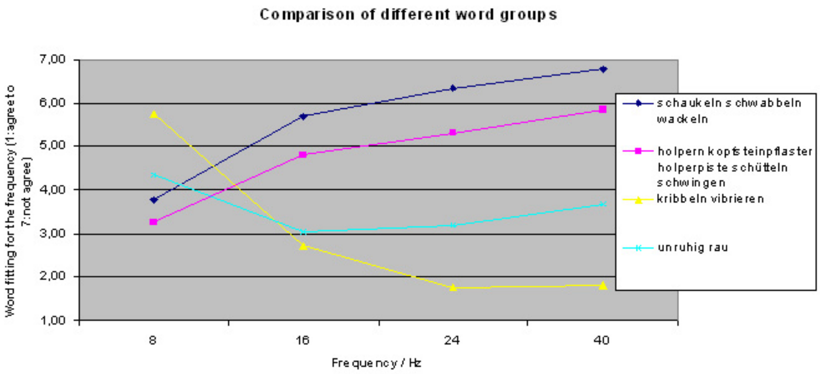

Figure 5.2.: Mean values of the definitions belonging to the different factors as a function of the excitation frequencies; from 1-agree to 7-disagree.

The characteristic for “unruhig” and “rau” is not varying strong over frequency but has a maximum for the frequency range were the other two factors overlapp.

5.4. Discussion

In the results of this experiment there can be seen that the definitions for the denominations of the perception can be sorted in groups which either describe constant movements (first factor in figure 5.1) or unsteady movements (second factor in figure 5.1).

The use of these definitions depends on the excitation frequency as can be seen in figure 5.2. The resolution seems to be quite rough in this experiment and it is not evident that the chosen frequencies fit to the different perception regions.

But still there can be seen that the different definitions clearly describe different perceptions, and these are correlated to the frequency.

There are only some words showing no clear frequeny dependence (third factor in figure 5.1). these words are “unruhig” and “rau”.

6. Analysing perceptual dimensions with a semantic differential

6.1. Aim

In the third experiments, the results from the free verbalisation experiment and the pre-experiment are used, to get more detailed information about the perception dimensions for sinusoidal whole body vibration with excitation in vertical (-z) direction.

In the free verbalisation experiment the factor analysis led to six different frequency regions. The middle frequencies of these regions (4 Hz, 8 Hz, 12 Hz, 20 Hz, 25 Hz, 40 Hz) were chosen for a new analysis with a semantic differential.

6.2. Method

Two different kinds of semantic differentials were designed. One of the differentials had more words and in exchange an easier task, while the other one asked more detailed for the perception, but for less words. Both questionaries were in German.

The first one was with 31 words. Most of the words were selected from the results of the free verbalisation experiment, and some semanticly fitting words were added. All used words and their translation to English can be seen in the appendix in table .2 The task was : "Are the following words describing your perception? (Yes / No)". The semantic differential handed to the probands can be seen in the appendix in figure .5.

In the second semantic differential 18 words found in the first experiment and with a equidistant scale in 7 steps from "agree (trifft zu)" to "dissagree (trifft nicht zu)" were used. It can be seen in the appendix in figure .6

Both experiments were done three times for every frequency splitted to two different days. The frequencies were presented in random order.

Signals All signals were generated and calibrated in Matlab. The calibration values for the sinusoidal excitation signals were calculated for every frequency at the beginning of every measurement date for every person, so that all frequencies had the same perceived level. The levels were adjusted in a way, that the probands mentioned them as well noticeable.

They were also adjusted after the equal level contures measured by [3]. The levels were for 4 Hz: 95 dB(ISO), for 8 Hz: 96.5 dB(ISO), for 12 Hz: 97.5 dB(ISO), for 20 Hz: 98 dB(ISO), for 25Hz: 99 dB(ISO) and for 40 Hz: 100 dB(ISO).

Participants 25 probands which are all native German speakers took part in the experiment. The average age was 23.2 years with a maximum of 36 years and a minimum of 20 years. The average weight was 73 kg, with a maximum of 110 kg and a minimum of 52 kg. The average hight was 175.9 cm with a maximum of 196 cm and a minimum of 157 cm.

Performance Every proband has been instructed in the same way. The performance sheet can be found in figure .3 and the instruction sheet in figure .4. The questionaries can be found in figure .5 and .6. The probands all participated on their free will and were informed that they could stop the experiment at every time. They all got an allowance.

6.3. Results

6.3.1. Semantic differential with 31 items

In figure 6.1 the medium values over all probands and the three repetitions for all items and for the six different frequencies are shown.

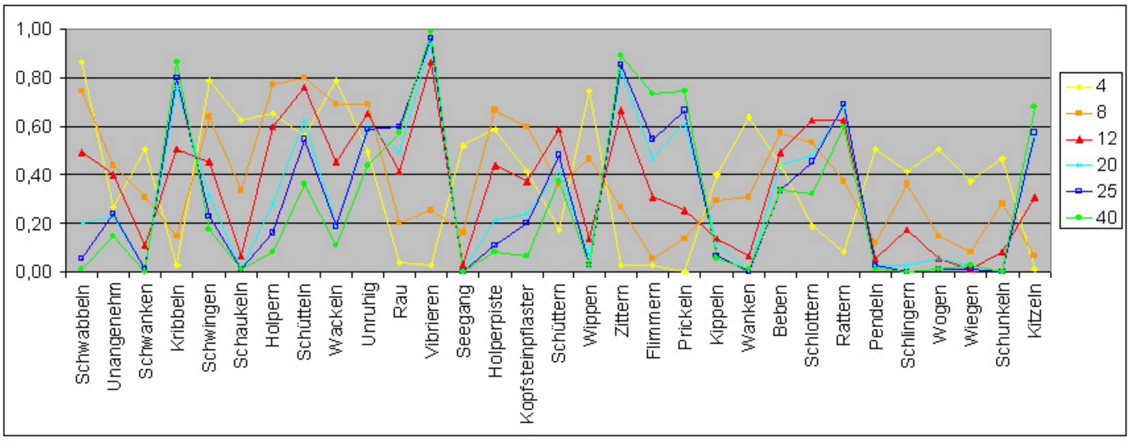

Figure 6.1.: Raw results of the semantic differential with 31 items. One can see the medium values over all probands and the three repetitions for all items and for the six different frequencies. The scale goes from 1 (all agree) to 0 (all disagree)

The task for the probands was to mark if the items describe the perception or not. In figure 6.1 one indicates that all probands marked that the description is fitting to the perception while zero means that none of them agree.

One can see that different frequencies are described by different words. The characteristics for 4 Hz and for 8 Hz are nearly diametrical to those for 20 Hz, 25 Hz and 40 Hz. Specially 20 Hz and 25 Hz have very similar characteristics.

A factor analysis for the descriptions over the answers of all probands found five different groups of items. The component matrix can be seen in table 6.1 The KMO was 0.917, so that the data could be assumed as interpretable.

The criteria for the Factors was that the Eigenvalue should be more than 1. The reasonability of the resulting amount of factors was also controlled in the Screeplot. The Screeplot can be found in the Appendix in figure .7.

Rotated Component Matrix

	Component				
	1	2	3	4	5
schaukeln	0,768	-0,246	0,056	0,098	-0,039
wogen	0,760	-0,045	-0,207	-0,015	0,154
wanken	0,755	-0,257	0,030	0,016	-0,086
pendeln	0,741	-0,103	-0,099	-0,040	0,001
schwanken	0,698	-0,225	0,070	-0,034	-0,037
Seegang	0,663	-0,239	-0,083	0,086	-0,071
schunkeln	0,646	-0,271	0,051	0,100	-0,020
wiegen	0,610	0,010	-0,262	-0,210	0,225
wippen	0,596	-0,382	-0,071	0,010	0,122
kippeln	0,475	-0,106	0,259	0,041	0,094
wackeln	0,462	-0,336	0,392	-0,020	0,158
schlingern	0,429	-0,318	0,255	0,093	-0,306
schwingen	0,364	-0,207	0,213	-0,331	0,156
prickeln	-0,180	0,756	0,018	-0,085	-0,046
kribbeln	-0,286	0,748	0,069	-0,057	-0,105
flimmern	-0,117	0,728	-0,024	0,071	0,043
kitzeln	-0,166	0,698	0,133	-0,083	-0,059
zittern	-0,385	0,648	0,098	0,027	0,008
vibrieren	-0,514	0,611	-0,091	0,103	0,025
schwabbeln	0,418	-0,542	0,234	-0,006	0,214
rattern	-0,256	0,481	0,385	0,173	0,096
holpern	0,188	-0,477	0,288	0,260	0,443
Holperpiste	0,226	-0,442	0,190	0,293	0,419
schütteln	0,054	-0,031	0,685	0,024	-0,001
schlottern	-0,108	0,134	0,674	0,094	-0,033
schüttern	-0,070	0,334	0,520	0,139	0,214
Kopfsteinpflaster	0,011	-0,383	0,420	0,200	0,273
unangenehm	0,082	-0,114	0,075	0,735	-0,007
unruhig	0,063	-0,034	0,165	0,703	0,073
rau	-0,209	0,479	0,091	0,493	0,083
beben	-0,003	-0,019	0,062	-0,008	0,797
% Variance	19,621	16,601	7,272	5,671	4,749

Table 6.1.: Factor loadings of the items of the semantic differential with 31 items. In the lowest line the variance contingent which is clarified by the factor is shown.

The items "schaukeln", "wogen", "wanken", "pendeln", "schwanken" etc. show high loadings on the first factor.

All of these items seem to describe motions where the temporal development of the movement is clearly detectable with the whole body. All these items also contain an impression of a strong movement.

The second factor contains items like “prickeln”, “kribbeln”, “flimmern”, “vibrieren” and “rattern”. Most of these items are used to describe small movements which can be mainly felt on the skin and not with the whole body. Only “rattern ” might also describe strong sensory impressions.

The items “schwabbeln”, “holpern”, and “Holperpiste” are also loading on the second factor, but with a negative sign, so they are describing the opposite characteristic to the other items. All of them are describing slower motions and also the movements can be assumed to be stronger.

On the third factor the items “schtteln”, “schlottern”, “schttern”, and “Kopfsteinpflaster” are loading. They all describe strong sensory impressions with can be felt with the whole body. But these kind of motions are faster than the ones in the first factor.

The fourth factor contains the items “unangenehm”, “unruhig”and “rau”. They are describing a kind of comfortness or pleasantness of the signal, without containing much information about the signal itself.

The fifth factor is only containing the item “beben”, which seems not to fit to all of the other items.

To see the frequency behavior of the factors, there has been done a plot (figure 6.2) were the medium values over all three test repetitions, all test persons and over those items with the highest loadings in the factors were plotted. The items in the first factor describe the 4 Hz signal quite well, but for higher frequencies, they are no good descriptors. The mean value droppes already for 8 Hz quite strong.

The items in the second factor also show a strong frequency dependency. The higher the frequency is the better the items are describing the impression. And for the items with the negative sign it is exactly vice versa. They describe the lowest frequencies best.

The items like “schtteln” and “schlottern” describe the frequency s at 8 Hz and 12 Hz best. But there is not such a strong decay for the mean value as for the first two factors.

The fourth and the fifth factor look quite similar in this plot. They have no strong frequency dependence. Just slightly higher values for 8 Hz.

The value of the loading of the items in the factor analysis can not be directly used to interpret if the single items can be used to describe special frequencies.

Looking at the mean values over the three repetitions and over the probands for all items and the frequencies, sorted after the factors and the loadings (table .3 in the Appendix) it is becoming more clearly how well each item describes the perception of the different frequencies. A gain of 1 means that all probands judge in all runs the description as fitting to the perception, while 0 means that the description is not adequate to anyone’s perception.

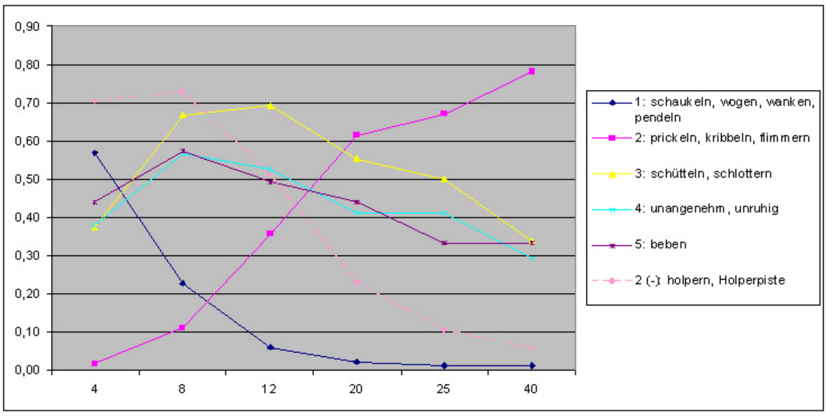

Figure 6.2.: Plot of the different factors over frequency for the semantic differential with with 31 items.

It can be seen that those items with the highest loading in the factor analysis, are not automaticly those with the highest mean value for the described frequency range. For example "wogen" has a high loading (0.76) but a mean value for 4 Hz of 0.507 what means that nearly half of the probands marked that item as not fitting to the perception. Another example is "schwingen" which have the lowest loading in the first factor but a mean value of 0.79 for 4 Hz. This is the highest mean value of all items in the first factor.

The standard deviation is not delivering much more information than the mean values in an experiment with only two alternatives. Still one can see that it is growing when more probands mark that the items are fitting to the perception. It is interesting that the standard deviation becomes lower when the item describes the perception badly. It seems that it is easier to detect if a perception can not be described as if it can be described.

For the first factor 4 Hz has the highest mean value for all items. For the higher frequencies the mean value is dropping fast.

But not all of the items in this factor have high mean values. "Schunkeln", "wiegen", "kippeln" and "schlingern" never have high values. They never describe the situation well, but still they describe low frequencies best.

Also a bit different from the other items in the first factor are the items "wackeln" and "schwingen". They have the highest mean value for 4 Hz but still for 8 Hz the mean value is quite high. For the higher frequencies they do not drop as fast as for the other items.

In the second factor the items have higher maximum mean values and lower standard deviations as the items in the first factor.

Therefore these items are easier to define in frequency.

Most items in the second factor with positive loading have the highest mean value for 40 Hz. “Vibrieren” has the highest mean value with 0.9867. But it has also quite high values over 0.86 for 8 Hz, 12 Hz, 20Hz, and 25Hz. The items “zittern” and “kribbeln” have mean values over 0.76 down to 20 Hz. For 12 Hz they drop slightly but they still have a mean value over 0.5. The items “prickeln” and “kitzeln” have slightly lower (at least 0.08) but still values above 0.56 also for 25 Hz and 20 Hz. The values for “flimmern” drop quite straight with lower frequency.

“Rattern” has similar mean values for the frequencies from 12 Hz to 40 Hz and a slight maximum at 25 Hz.

The items “schwabbeln”, “holpern” and “Holperpiste” have a negative loading on the second factor in the factor analysis, but however they have the highest mean values for the low frequencies, “schwabbeln” for 4 Hz and “holpern” and “Holperpiste” for 8 Hz. “Schwabbeln” and “holpern” have also strong values for the neighboring frequencies while the value for “Holperpiste” drops quite fast to higher frequencies.

The items in the third factor have the highest mean values between 8 Hz and 12 Hz. “Kopfsteinpflaster” has a clear maximum mean value (0.6) at 8 Hz, and for all other frequency they are below 0.42. “Schtteln” has a mean value of 0.8 for 8 Hz, but also for all other frequencies besides 40 Hz the mean value is higher than 0.5. “Schlottern” and “schttern” have their maximum at 12 Hz and slightly drop to higher and lower frequencies.

In the fourth factor the items “unangenehm” and “unruhig” have the highest mean value for 8 Hz. “Unangenehm” has always quite low mean values. So most of the probands never felt the signals as uncomfortable, but the frequencies 8 Hz and 12 Hz seem to be a bit more uncomfortable than the others. “Unruhig” has mean values over 0.55 for all frequencies beside 4 Hz and 40 Hz.

“Rau” has the highest mean value (0.6) for 25 Hz. For 40 Hz its also quite high with 0.5733. To the lower frequencies it drops.

The fifth factor is only containing the item “beben”. The highest mean value is 0.5733 for 8 Hz. The lowest mean value is 0.3333, so the difference for the frequencies is not that strong. It seems that the probands had problems with this item.

The next step was to find a stronger criteria, so for every proband only those results were counted as yes were he/she said yes in every run. The same for no. All values in the middle were set to zero and not counted. The table can be found in the Appendix in table .4

Looking at these results averaged over all probands one can find some items which never have a value over 0.2, so they never describe the situation well at all. These items are “unangenehm”, “schwanken”, “Seegang”, “schttern”, “kippeln”, “beben”, “pendeln”, “schlingern”, “wogen”, “wiegen” and “schunkeln”.

For “schwanken”, “wogen” and “Seegang” some of the probands mentioned in the interview that already the movement of 4 Hz was to fast for this description. I is difficult to decide if these words might describe a different group of low frequency perceptions, since the limit for playing vibrations on the platform is between 3 Hz and 4 Hz.

For “kippeln”, “pendeln”, “schlingern”, “wiegen” and “schunkeln” some probands mentioned that these item have in their interpretation a vertical component in the movement. That is the reason why they marked them as not describing the situation.

The highest values can be found either for the lowest or for the highest frequency. The items “schwabbeln”, “schwingen”, “schaukeln”, “wackeln” and “wippen” seem to describe the perception of a sinus at 4 Hz good, while the items “kribbeln”, “vibrieren”, “zittern”, “flimmern”, “prickeln” and “kitzeln” describe the perception of 40 Hz good.

There can be also found some items with the highest value for other frequencies. For 8 Hz that are the items “holpern”, “schtteln”, “unruhig”, “Holperpiste” and “Kopfsteinpflaster”, for 12 Hz it is “schlottern” and for 25 Hz it is “rau” and “rattern”.

The only frequency were no item has a maximum is 20 Hz.

6.3.2. Semantic differential with 18 items

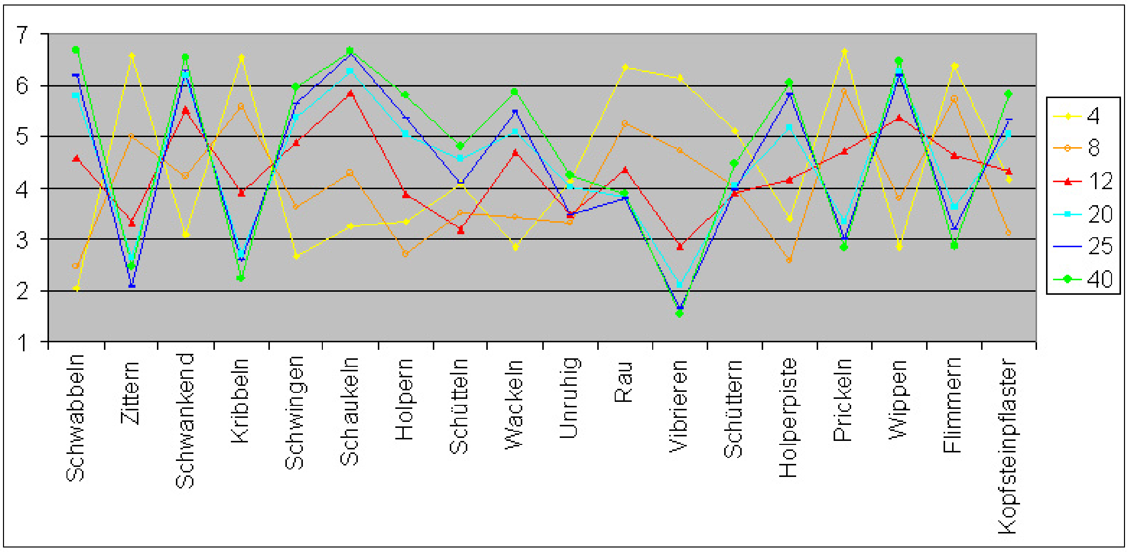

Figure 6.3.: Raw results of the semantic differential with 18 items. One can see the medium values over all probands and the three repetitions for all items and for the six different frequencies.

In figure 6.3 one can see the mean values over all probands and the three repetitions for all items and for the six different frequencies for the experiment with the semantic differential out of 18 words. The task was to mark how well the items describe the perception on a scale in seven steps.

In figure 6.3 when all probands marked that they agree that the description fits to the perception this results in 1 while 7 means that none of them agree.

Rotated Component Matrix			
	Component		
	1	2	3
Schaukeln	0,803	-0,258	0,138
Schwankend	0,778	-0,225	0,076
Wippen	0,701	-0,306	0,182
Wackeln	0,696	-0,109	0,317
Schwingen	0,681	-0,15	0,021
Schwabbeln	0,637	-0,447	0,267
Prickeln	-0,226	0,819	-0,263
Kribbeln	-0,329	0,783	-0,234
Zittern	-0,394	0,754	-0,027
Flimmern	-0,277	0,698	-0,191
Vibrieren	-0,522	0,644	-0,123
Schüttern	0,22	0,629	0,415
Rau	-0,31	0,528	0,356
Holpern	0,358	-0,205	0,69
Holperpiste	0,388	-0,265	0,673
Kopfsteinpflaster	0,206	-0,103	0,644
Unruhig	-0,21	-0,046	0,576
Schütteln	0,333	0,329	0,564
% Variance	24,332	22,82	14,996

Table 6.2.: Factor loadings of the items of the semantic differential with 18 items. In the lowest line the variance contingent which is clarified by the factor is shown.

The results for 20 Hz, 25 Hz and 40 Hz show quite similar characteristics. The characteristic for 4 Hz is nearly diametric to that of the frequencies 20 Hz, 25 Hz and 40 Hz. 8 Hz has a similar characteristic as 4 Hz but less distinct, more around the middle values.

The data for the second questionary was analysed with a varimax rotated factor analysis and the component matrix can be seen in table 6.2 . The KMO was 0.917, so that the data could be assumed as interpretable. The criteria for the Factors was that the Eigenvalue should be more than 1. The reasonability of the resulting amount of factors was also controlled in the Screeplot. The Screeplot can be found in the Appendix in figure .8. The analysis results in three factors.

The first factor contains item like “schaukeln”, “schwanken” and “wippen”. They describe kind of motions where the movement is clearly detectable with the whole body. All these items also contain an impression of a strong movement.

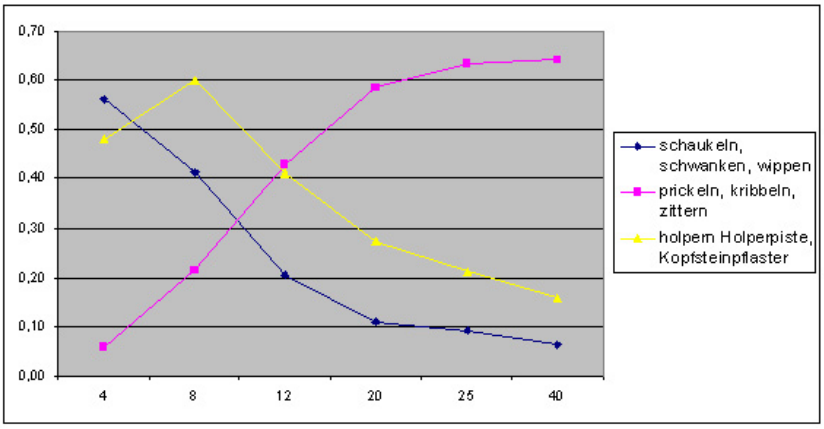

Figure 6.4.: Plot of the mean values of three items with the highest loading for the different factors over frequency for the semantic differential with 18 items.

The second factor contains items like “prickeln”, “kribbeln”and “flimmern” These items are used to describe small movements which can be mainly felt on the skin and not with the whole body.

The third factor contains the items “holpern”, “Holperpiste”, “Kopfsteinpflaster” and “schtteln”, which describe quite similar perceptions. All of them describe strong impressions which can be felt with the whole body, but which are not very harmonic. On the same factor there are also loading the item “unruhig”, which might explain quite good the characteristic of the whole factor. In comparison to the other factors these items all seems to describe more unsteady perceptions.

Looking at the mean values over all runs and all probands and over those items with the highest loadings in the factors (Fig. 6.4) one can see that the factors have a different but strong frequency dependency. The first factor describes low frequencies well. This factor describes frequencies around 4 Hz best. The third factor describe also low frequencies. But this factor describes those frequencies best which are around 8 Hz. The second factor is vise versa to the first factor. It describes the high frequencies best.

Looking at the mean values over the runs and over the probands for all items and the frequencies, sorted after the factors (table .5 in the appendix) one can see how the items describe the different frequencies. For the mean values, 1 means that all probands answers in all runs that the description fits very good to the perception, while 7 means that the description does not fit for anyone, so 4 would be the middle.

All items out of the first factor have a mean value below 3.25 for 4 Hz and the value is growing for higher frequencies. The standard deviation is lower than 2 for all values. So the items in the first factor seem to be good descriptors for frequencies around 4 Hz.

The items out of the second factor have their lowest mean values for the high frequencies (25 Hz and 40 Hz), "Schttern" has quite similar values for two frequencies, for 25 Hz (3.97) and for 12 Hz (3.92). "Prickeln", "kribbeln" and "flimmern" have the lowest mean values for 40 Hz. But they have also low values (below 3.2) for 25 Hz. "Vibrieren" has the lowest mean value of all the items in this factor of 1.55 for 40 Hz, but it has low mean values for the frequencies down to 12 Hz (below 2.9). The items "zittern" and "rau" have the lowest mean value for 25 Hz. The mean value grows more to the lower frequencies than to 40 Hz. There the difference is below 0.5 and much smaller than the standard deviation which is below 2.2.

In the forth factor the items "holpern", "Holperpiste", "Kopfsteinpflaster", and "unruhig" have the lowest mean value for 8 Hz. Only "schtteln" has the lowest value at 12 Hz.

For both experiments there has been done a factor analysis over the probands. The results does not show any interpretable influence on the response behavior of the probands, as can be seen in table .6 in the appendix.

6.4. Discussion

For some of the frequencies there can be found describing items.

The perception of sinusoidal signals around 4 Hz can be described as “schaukeln”, “schwanken” or “wippen”. Around 8 Hz the perception is more like “holpern” or “Kopfsteinpflaster”.

For the frequencies in the middle of the investigated frequency range the description seems to be more complicate. The frequency regions found in the free verbalisation experiment are more described by the overlap of different descriptors. For 12 Hz the description “schtteln” and “schlottern” still describe the perception good. “Zittern” and “Schttern” are describing signals about 25 Hz the best. But they do not seem to be clear descriptors for the probands.

For 40 Hz there are some descriptors fitting good to the perception, like “prickeln”, “kribbeln”, “flimmern” and “kitzeln”. 20 Hz is the only frequency were no descriptors can be found.

These results can be found in the experiments with both kinds of semantic differentials.

For the factor analyses for the two semantic differentials and those items used in both questionaries, the first factor are similar. Only the word “schwabbeln” is loading on different factors in the two experiments. The positive loadings on the second factor are also quite similar, but in the semantic differential with 31 items there are also items with negative loading on the second factor. The third factor in the semantic differential with 18 items is divided to different factors in the analysis of the other semantic differential. Only “holpern” and “Holperpiste” are loading on the same factor for both kind of semantic differentials.

7. Main Discussion

The results of the experiments show that with the help of the found denominations, specific perceptions (which can be felt by an excitation) of whole body vibration (while a sinusoidal frequency sweep) can be related to different frequency regions. This is shown in 4.1.

There were found different percepted frequency regions (table 4.2). The lowest one going up to 6 Hz, the second one going up to 9 Hz, the third one going up to 19 Hz, the fourth one up to 22 Hz, the fifth one up to 27 Hz and the sixth one for the high frequencies.

For some of these groups describing denominations can be found but for the the groups around 20 Hz and 25 Hz there were no clear descriptors found.

There are just some definitions without clear frequency dependence as can be seen in 5.2, 6.2 and 6.4.

The definitions for the denominations of the perception can further be sorted in groups which either describe constant movements or unsteady movements as can be seen in 5.1. The use of these definitions depends on the excitation frequency.

An hypothesis for the big difference between the perception of vibration below 12 Hz to those higher than 20 Hz could be , that the low vibrations are percepted as a changing movement with time, while the higher vibration are really a perception of frequencies.

The results of the first two experiments have been presented at the DAGA ([15])

Part III.

Comodulation detection differences (CDD) for vibration

8. Introduction

In the previous chapters the perception of whole body vibrations had been analysed on the basic of sensation. This chapter uses a different approach of psychoacoustics, which is the estimation of thresholds. In this experiment the thresholds for different masked signals were measured.

For hearing there are masking patterns known, in form of filters with a maximum for signal and masker on frequency([10]).

Bellmann and Ewert in [4] already used this approach to measure masking patterns for sinusoids masked by $\frac{1}{2}$ octave narrow band noise for vibrations.

Based on the results of Bellmann and Ewert a further interest in this part of the thesis was to find out more about the perception of level fluctuations. For this a two alternative force choice (2AFC) experiment has been done. The aim was to analyse if there can be found differences in the perception of coherent or incoherent fluctuations of the level.

Following this idea a bit further there appeares the question if there can be found detection threshold differences between sinusoidal signals, comodulated narrow noise and uncorrelated narrow noise.

9. Background

There has been shown by Bellmann and Ewert in [4] that there are filters existing for the perception of vibration. They used sinusoids with signal frequencies of 4 Hz, 8 Hz, 16 Hz and 32 Hz. The masker bandwidth was $\frac{1}{2}$ octave narrow band gaussian noise, and the center frequency varied from 4 Hz to 64 Hz. They show masking patterns with a maximum when signal frequency and masker frequency are the same, for the so called on-frequency condition. The threshold patterns look similar for the different signal frequencies, and have a non-symmetric shape. For the signal frequencies 16 Hz and 32 Hz the shape of the patterns seem to be the same on a logarithmic frequency scale. The slope of the upper edge was similar for all center frequencies.

This kind of experiments have already been done in the field of hearing.

The idea of these kind of experiments is to find out more about the ways of perception of comodulated and uncorrelated Signals.

First basic experiments have been done around 1987 by Cohen et al. for example in [10]. They found out that there is existing a process for the perception which is overall in the frequency range. They have shown that for hearing, the measured detection thresholds are lower for independent temporal envelopes of noise bands than for correlated envelopes.

Also Moore and Borrill worked a lot about this topic. They found out that the perception thresholds for sinusoidal signals and uncorrelated signals are similar, while the thresholds for comodulated signals are higher in [18]. They named this effect as comodulation detection difference (CDD).

They also tried to find models to explain the CDD effect ([7]). The main explanation is that the signals are analysed by "within channel cues". Another idea of them is that for comodulated signals, minima in level submit no information, while for sinusoids and uncorrelated signals, the minima of masker and signal are not the same and so can be useful to differ between the signals.

Buschermhle in [9] follows the ideas of Borill and Moore. But he uses a different approach to explain CDD. To model CDD he used compressed envelopes

S.Ernst and J.Verhey in [12] do not follow the ideas of Buschermhle, but assume a suppression of the signal by the masker.

To do this kind of experiments the perception has to show a clear frequency selectivity. This has been shown by [3] and [4] for vibration. The signals used in the following experiment were orientated on the used values by M.Bellmann and S. Ewert in [4].

The same signal frequencies were chosen, as they used in their experiments, for the two filters they could measure for both sides. The root-mean-square level for the masker was set to 100 dB(ISO) as they did.

10. Experiment

10.1. Method

To compare the perception thresholds of a masked signal in vibration for a sinusoid, a comodulated narrowband noise and a uncorrelated narrow band noise, a two interval alternative forced choice experiment (2AFC) with a one up two down rule in each interval has been designed.

An alternative forced choice experiment contains different signals played in random order. The probands have to select one of the signals. In this experiment two signals were played to the probands in one run. One contains only the masker and the second one contains masker and the signal to be detected.

For the experiment the same set-up had been used as for the first experiments. The signals were generated in a computer with Matlab and were then send via the DA-converter to the shaker on the platform. For this experiment the Matlab based AFC package developed by Stephan Ewert has been used.

10.2. Signals

The experiments have been done for two center frequencies (f_s): 16 Hz and 32 Hz. The signal was fixed to this frequencies, while the masker varies in frequency in five steps of $\frac{1}{2\sqrt{2}}f_s$, $\frac{1}{2}f_s$, f_s, $2f_s$ and $2\sqrt{2}f_s$. For the signal frequency of 16 Hz, this results in the middle frequencies 5.65 Hz, 8 Hz, 16 Hz, 32 Hz and 45.25 Hz for the masker, and in the middle frequencies of 11.31 Hz, 16 Hz, 32 Hz, 64 Hz and 90.5 Hz for the signal frequency of 32 Hz.

The bandwidth for the narrow noise bands was set to a half octave around the signal frequency, so either 5.75 Hz for 16 Hz as signal center frequency or 11.14 Hz for 32 Hz as signal center frequency. The same bandwidth as for the signals was used for the masker to keep the energy in the bands constant.

The narrow band noises where created from random Gaussian noise in Matlab and was newly created for every presentation.

The root-mean-sqare level of the masking noise band was always set to 100 dB(ISO), and also the starting level for the signal was set to 100 dB(ISO).

There can be seen two recorded example signals in figure 10.1. For both signals the difference between the level of the signal and the distorsions is more than 30 dB.

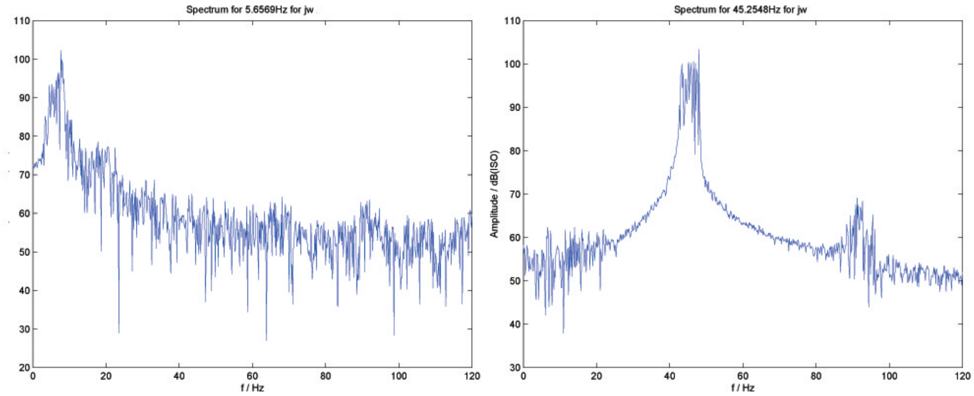

Figure 10.1.: Spectra for two of the used narrow noise signals. Both were recorded with an accelometer below the chair with the seated proband. Both signals had a bandwidth of 5.75 Hz and a root-mean-square level of 100 dB(ISO). The left signal is centered around 5.65 Hz and the right signal is centered around 45.25 Hz

For the signal around 5.75 Hz it is noticable that the level in the signal droppes from 100 dB(ISO) at ca. 9 Hz to ca. 90 dB(ISO) at ca. 3 Hz. This is due to the limits of the used shaker.

10.3. Participants

Three probands participated in the experiment since the measurement for one proband was already 7 hours.

The probands were volunteers. They were informed that they could stop the experiment at every time. They were paid for participaiting in the experiment.

To minimise the measurement time only probands were invited who were trained in AFC and already participated in vibration experiments.

The average age was 26.6 years, with a maximum of 48 years and a minimum of 25 years, the average height was 182.3 cm, with a maximum of 190 cm and a minimum of 175 cm and the average weight was 71.64 kg, with a maximum of 75 kg and a minimum of 68 kg.

10.4. Task and Performance

The task for the probands was to mark that interval, which they assumed to contain both masker and signal and not only the masker. The amplitude of the signal was subsequently changed to find the perception threshold adaptivly.

The whole experiment has been repeated three times for every condition for every proband. As the total duration of the measurement for one proband was 7 hours, the measurement has been divided into several parts depending on the concentration ability of the probands.

The probands got a feedback after every interval of the experiment if they had marked the wrong or the correct signal.

At the end of every experimental run, a short interview has been done with the probands. They were asked to describe freely their impression of the signals and the experiment.

10.5. Level Correction

Before the results of the experiment were plotted, a correction for the level values of the comodulated on-frequency condition has to be done to facilitate the comparison with the data of the other target signals. The motivation for this transformation is that for the comodulated on-frequency condition the amplitude of the signal and masker add, whereas for the other signals types the intensity adds.

For uncorrelated and tonal signals the total intensity equals to

$$I_{tot} = \overline{A_{tot}}^2 = \overline{A_{mask}}^2 + \overline{A_{sig}}^2 \tag{10.1}$$

where the index *mask* denotes the masker and the index *sig* denotes the signal. For comodulated signal the amplitudes add, i.e. the total intensity is equal to

$$I_{tot} = I_{mask} + I_{sig} \tag{10.2}$$

At the threshold the signal amplitude is a function of the masker amplitude. With $S_{sig}(t) = \frac{1}{k} S_{mask}(t)$ one comes to

$$\begin{aligned} I_{tot} &= \frac{1}{T} \int \left(S_{sig}(t) + S_{mask}(t)\right)^2 \mathrm{d}x && (10.3) \\ &= \frac{1}{T} \int \left(S_{mask}(t)\right)^2 \cdot \left(1 + \frac{1}{k}\right)^2 \mathrm{d}x && (10.4) \\ I_{tot} &= \left(1 + \frac{1}{k}\right)^2 \cdot I_{mask} && (10.5) \end{aligned}$$

Since the absolute intensity and the absolute amplitude shall be the same and $I_{mask} = A_{mask}$:

$$\begin{aligned} I_{mask}(1 + \frac{1}{k})^2 &\stackrel{!}{\equiv} I_{mask} + I_{sig} && (10.6) \\ \Rightarrow (\frac{2}{k} + \frac{1}{k^2}) I_{mask} &= I_{sig} && (10.7) \end{aligned}$$

This results in

$$k = 10^{(\frac{L_{A_{mask}} - L_{A_{sig}}}{20})} \tag{10.8}$$

and for the Levels in

$$10\log(\frac{2}{k} + \frac{1}{k^2}) + L_{I_{mask}} = L_{I_{sig}} \tag{10.9}$$

11. Results

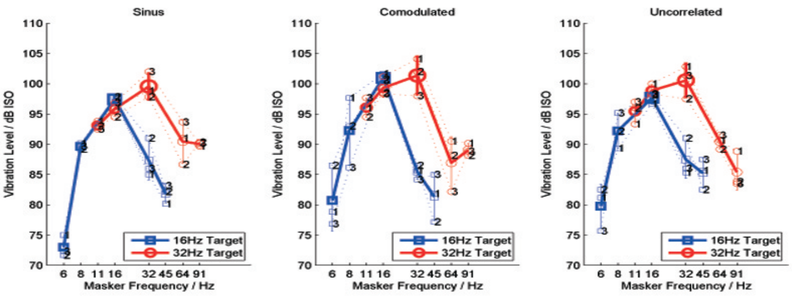

Figure 11.1.: Results for the 2-AFC experiments for the proband AE. The main lines are the results averaged over the three repetitions while the dotted lines are the individual repetitions, marked by their order. The blue line (squares) stands for the signal frequency at 16 Hz, the red line (circles) for the signal at 32 Hz.

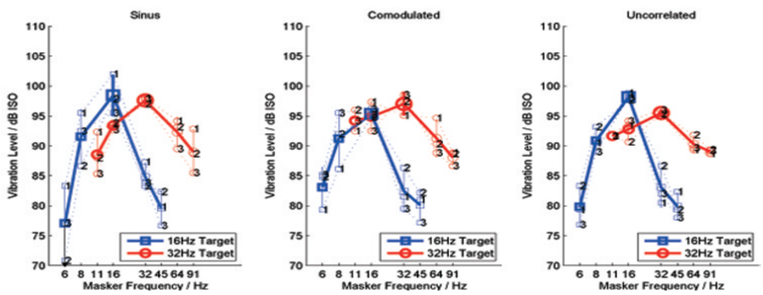

Figure 11.2.: Results for the 2-AFC experiments for the proband JW. The solid lines are the results averaged over the three repetitions while the dotted lines are the individual repetitions, marked by their order. The blue line (squares) stands for the signal frequency at 16 Hz, the red line (circles) for the signal at 32 Hz.

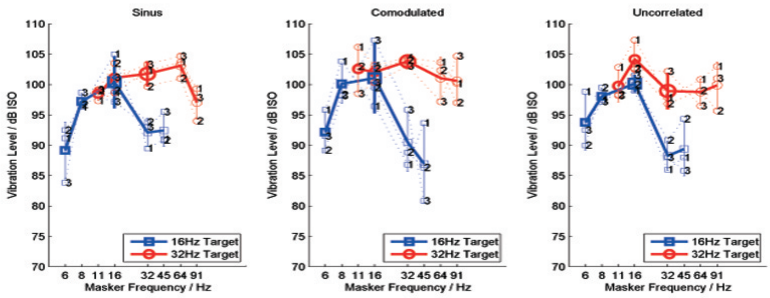

Figure 11.3.: Results for the 2-AFC experiments for the proband LH. The solid lines are the results averaged over the three repetitions while the dotted lines are the individual repetitions, marked by their order. The blue line (squares) stands for the signal frequency at 16 Hz, the red line (circles) for the signal at 32 Hz.

In figure 11.1, 11.2 and 11.3,the results of the three probands for the three test conditions conditions are shown.

The solid lines represent the results averaged over the three repetitions while the dotted lines are the single repetitions, marked by their order. The blue line (squares) is used for the signal frequency centered at 16 Hz, the red line (circles) for the signal around 32 Hz.

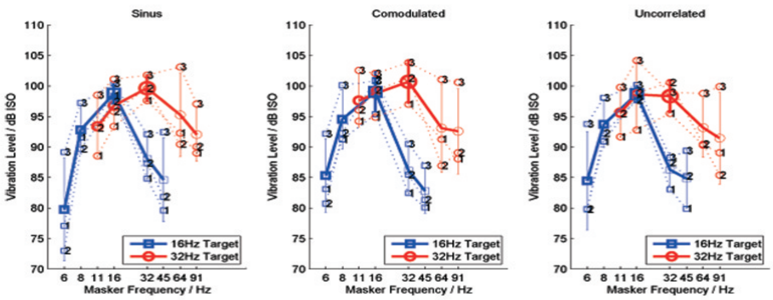

Figure 11.4.: Results for the 2-AFC experiments averaged over the mean values of the probands. The solid lines are the results averaged over the three repetitions while the dotted lines are the individual repetitions, marked by their order. The blue line (squares) stands for the signal frequency at 16 Hz, the red line (circles) for the signal at 32 Hz.

For the probands AE and JW, the maximum for all conditions and both signals occur always when masker and signal had the same average frequency.

Only the proband LH does not show this for the signal frequency of 32 Hz. This proband seems to have problems with the whole measurement and specially with the uncorrellated condition. LH had also mentioned in the interview that some conditions were hard to judge.

Figure 11.4 shows the averaged mean values of the results of the three probands.

The solid lines represent the results averaged over the three repetitions while the dotted lines are the mean answers of the probands, marked with 1 for JW, 2 for AE and 3 for LH. The blue line (squares) stands for the signal frequency at 16 Hz, the red line (circles) for the signal at 32 Hz.

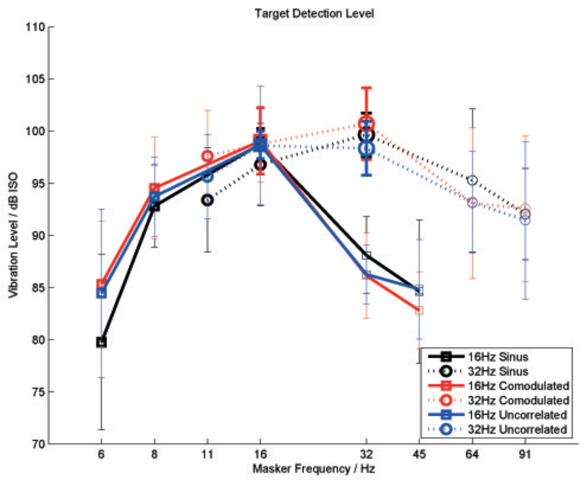

Figure 11.5.: The results averaged over the probands for the three different kinds of signals plotted together. The squares mark the values for the signal frequency at 16 Hz, the circles those for the signal frequency at 32 Hz. The red lines stand for the comodulated signals, the blue line for the uncorrelated signals and the black line for the sinusoids.

In figure 11.5 the averaged mean values of all probands for the three different conditions are plotted together to compare them easily.

The values for the three different conditions are nearly identical compared to the size of their errorbars.

12. Discussion

As expected according to [4], filters for the masked detection thresholds for sinusoidal signals and also for the comodulated and uncorrelated narrow band noises can be found. For all probands it can be seen that the filter for 32 Hz is flatter and wider than the one for 16 Hz. This is different to the results [4] shows. There, size and shape of the filters are similar for the two frequencies.

It is remarkable that the first value (for the masker frequency at 5.6 Hz) is really low, specially for the sinus (figure 11.4). Looking at the results of the first experiment this might be, because 5.6 Hz lies in the first frequency range, while the signal of 16 Hz lies within the third group. So the signals are percepted differently, and therefore are not influencing the perception of each other.

Another fact that supports this hypothesis is that some of the probands mentioned in the interview that they could differ between the masker and the signal for this frequencies due to different percepts.

This could also explain the lower value for the sinusoid compared to the narrow noises. Due to the bandwidth of the noise the signal and the masker both reached in the second frequency range, and so there was a little overlap in the perception while the sinusoid was only in the first perception region, and there was no overlap at all.

Another idea to explain the low first value for the sinusoid is that for noise bands at a center frequency of 5.6 Hz the lower part of the band comes into frequency regions, the shaker can not play back with the whole level, and so the intensity for those signals was lower. This effect can be seen in figure 10.1.

It can bee seen that the detection levels are very similar for the three conditions (in figure 11.5), so there seem to be no difference between comodulated and uncorrelated noise in the detection of vibration.

Looking in figure 11.4 at the on-frequency conditions one may thus conclude that there is no cue on the envelope. The results seem to indicate that the performance is based on energy detection, since all three conditions have nearly the same level.

Compared to the results for hearing discussed in chapter "Background" the vibration perception seem to use a long time average instead of different channels following the results of the done experiment.

The probands were not able to use minima in the uncorrelated or sinusoidal conditions. This could be an effect of the signal length , but with two seconds it was assumed to be long enough also for the low frequencies around 5 Hz.

Following this further, the question is if vibration perception is compressive at all and if there exists suppression for vibration. This might be an interesting question for further studies.

Other ideas for further experiments in this topic would be to use a 3AFC instead of the 2AFC, since the probands mentioned that the 2AFC was very complicate for co-modulated and uncorrelated vibration signals. This might lead to more distinct results.

To handle the length of the measurement time one could therefore think about using less measurement points. The filters would still be indicated quite clear without the highest and the lowest frequencies (5.6 Hz and 91 Hz).

Part IV.

Conclusion

There were several questions asked in this thesis: Are there words describing the different perceptions which can be generalised? How far does the perception change over the frequency range. Can the sensations be categorised in different groups of perception or are they just slightly changing? There were found answers to these questions:

For some of the frequencies describing items can be found.

The perception of sinusoidal signals at around 4 Hz can be described as "schaukeln", "schwanken" or "wippen". Around 8 Hz the perception is more described as "holpern" or "Kopfsteinpflaster".

For the middle frequency the description seems to be more complicate. For 12 Hz the description "schtteln" and "schlottern" still describe the perception good. "Zittern" and "Schttern" are describing signals about 25 Hz the best. But they do not seem to be clear descriptors for the probands.

For 40 Hz there are some descriptors fitting good to the perception, like "prickeln", "kribbeln", "flimmern" and "kitzeln".

The results of the experiments show that specific perceptions can be related to different frequency regions.

There were found different percepted frequency regions. The lowest one going up to 6 Hz, the second one going up to 9 Hz, the third one going up to 19 Hz, the fourth one up to 22 Hz, the fifth one up to 27 Hz and the sixth one for the high frequencies.

For some of these groups describing denominations can be found but for the the groups around 20 Hz and 25 Hz there were no clear descriptors found.

The found factors for the items can be used to differ between denominations describing either constant movements or unsteady movements. The use of these definitions also depends on the excitation frequency.

An hypothesis for the big difference between the perception of vibration below 12 Hz to those higher than 20 Hz could be , that the low vibrations are percepted as a changing movement with time, while the higher vibration are really a perception of frequencies.

There has also been used another approach for analysing the perception of vibration. This approach was to use thresholds of masked signals, as already Bellmann ([4]) did.

A further point of interest with this approach, was to find out a bit more about the perception of modulation, and if there are differences in the perception of coherent or incoherent fluctuations in level.

The filters found by Bellmann and Ewert were also found in this experiments, but the shape was different.

While Bellmann and Ewert got filters similar in size and shape for the different center frequencies, in this experiment the filters for the same freqencies were different. For 32 Hz the filters were flatter and wider than those for 16 Hz.

It can bee seen in the results of the second part of this thesis that the detection levels are very similar for the three conditions (sinusoid, comodulated narrow noise bands and uncorrelated narrow noise bands), so there seem to be no difference between comodulated and uncorrelated noise in the detection of vibration.

Looking at the on-frequency conditions one may thus conclude that there is no cue on the envelope. The results seem to indicate that the performance is based on energy detection, since all three conditions have nearly the same level.

The vibration perception seem to use a long time average instead of different channels following the results of the done experiment. The probands were not able to use minima in the uncorrelated or sinusoidal conditions to detect the signal.

Part V.

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Part VI.

Appendix

Appendix for: Free verbalisation

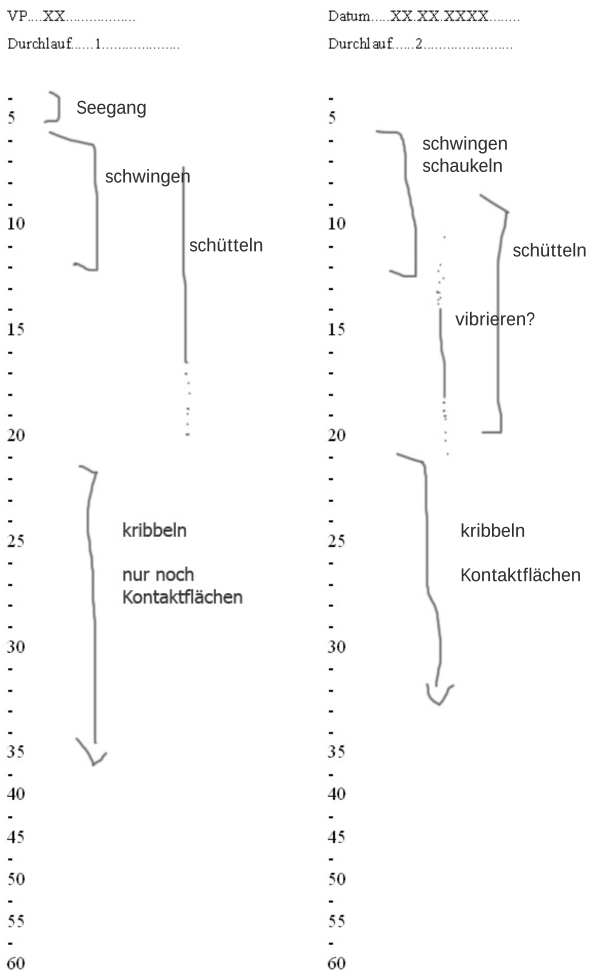

Figure .1.: Example scale how a answer protocol of the free verbalisation experiment looked like

Appendix for: Perception dimensions for sinusoidal oscillation excitation

German	English
schwabbeln	to wobble
unangenehm	unpleasant
schwanken	to oscillate
kribbeln	to tingle
schwingen	to swing
schaukeln	to rock
holpern	to jolt
schütteln	to shake
wackeln	to joggle
unruhig	fluttering
rau	rough
vibrieren	to vibrate
Seegang	motion of the sea
Holperpiste	bumpy road
Kopfsteinpflaster	cobblestone

Table .1.: The words used for the semantic differential and their translation to English

In wie weit lässt sich das taktile Signal durch die folgenden Begriffe beschreiben?

		1	2	3	4	5	6	7	
schwabbeln	trifft zu								trifft nicht zu
unangenehm	trifft zu								trifft nicht zu
schwankend	trifft zu								trifft nicht zu
kribbeln	trifft zu								trifft nicht zu
schwingen	trifft zu								trifft nicht zu
schaukeln	trifft zu								trifft nicht zu
holpern	trifft zu								trifft nicht zu
schütteln	trifft zu								trifft nicht zu
wackeln	trifft zu								trifft nicht zu
unruhig	trifft zu								trifft nicht zu
rau	trifft zu								trifft nicht zu
vibrieren	trifft zu								trifft nicht zu
Seegang	trifft zu								trifft nicht zu
Holperpiste	trifft zu								trifft nicht zu
Kopfsteinpflaster	trifft zu								trifft nicht zu

Signal........X Hz................ VP......XX.................... Datum....XX.XX.XXXX...........

Figure .2.: The semantic differential used in the preexperiment about perception dimensions

Appendix for: Analysing perceptual dimensions with a semantic differential

German	English
Schwabbeln	to wobble
Unangenehm	unpleasant
Schwanken	to oscillate
Kribbeln	to tingle
Schwingen	to swing
Schaukeln	to rock
Holpern	to jolt
Schütteln	to shake
Wackeln	to joggle
Unruhig	fluttering
Rau	rough
Vibrieren	to vibrate
Seegang	motion of the sea
Holperpiste	bumpy road
Kopfsteinpflaster	cobblestone
Zittern	to shudder
Flimmern	to jitter
Prickeln	to prick
Kippeln	to tilt
Wanken	to dodder
Beben	to quake
Schlottern	to shiver
Rattern	to chatter
Pendeln	to ply
Schlingern	to lurch
Wogen	to wollow
Wiegen	to cradle
Schunkeln	to sway (schunkeln)
Kitzeln	to tickle

Table .2.: The words used for the semantic differential and their translation to English

Ablauf: 1. Termin

- Instruktionsblatt und Einverstandnisserklärung geben und unterschreiben lassen

Kommentar	OK von VP
Pegel deutlich unter Bereich wo Risiko für Gesundheit	
Raten ab bei Schwangerschaft	
Raten ab bei Schwindel in der letzen Woche	

- 12 Signale zur Orientierung (jeden Termin) (6 Frequenzen in Reihe + vermischt (2 5 6 3 1 4))
- Kalibrierung aufnehmen
- wärend berechnen der Signale: 1.Fragebogen schon mal angucken
- dann Messung:(Signale gemischt nach Tabelle)
  Bewertungsbogen 1 angucken und messen
  Bewertungsbogen 2 angucken und messen
  Bewertungsbogen 3 angucken und messen

Nachbesprechung:

- Sind die Signale OK? ....
- Bei den Signalen noch was aufgefallen? ....
- fehlen Begriffe? ....
- Autofahrer oder Fahrradfahrer? ....
- ....

Datum	
Proband	
Alter	
Gewicht	
Größe	

Frequenzen

1: 4Hz	2: 8Hz	3: 12Hz	4: 20Hz	5: 25Hz	6: 40Hz

Reihenfolgen

- a) 2 4 6 1 5 3   8 20 40 4 25 12
- b) 4 1 3 6 2 5   20 4 12 40 8 25
- c) 3 5 1 4 2 6   12 25 4 20 8 40
- d) 5 3 6 2 4 1   25 12 40 8 20 4
- e) 6 4 1 3 5 2   40 20 4 12 25 8
- f) 1 3 5 2 6 4   4 12 25 8 40 20

1

Figure .3.: Proceeding sheet for the first measurement date of a proband. The second date was similar

Versuch I zu Ganzkörperschwingungen

Wahrnehmungen bei Ganzkörperschwingungen können sehr vielfältig sein. Sie sollen im folgenden Versuch erfasst werden. Der Versuchsablauf ist wie folgt:

Orientierungsphase
Um Sie mit den Phänomenen vertraut zu machen, die Sie im Versuch beurteilen sollen, wird zunächst die Plattform, auf der Sie sitzen, zu Schwingungen angeregt.

Individuelle Einstellung des Versuchsaufbaus
Der Versuchsaufbau wird jetzt auf Sie abgestimmt. Währenddessen sind von Ihrer Seite keine Aktivitäten erforderlich.

Beurteilungsphase
In der nun folgenden Beurteilungsphase erhalten Sie nacheinander drei unterschiedliche Sorten Beurteilungsbögen, anhand derer verschiedene Schwingungen bewertet werden sollen. Nachdem Sie sich jeweils mit den Begriffen eines Bogens vertraut gemacht haben und noch offene Fragen geklärt sind, wird die Plattform sechs mal zum Schwingen angeregt. Nach jeder Anregung werden Sie gebeten, einen Beurteilungsbogen auszufüllen.

Beurteilungsbogen 1 enthält Begriffe, bei denen Sie entscheiden sollen, ob diese während der einzelnen Schwingungsdarbietungen Ihre Empfindungen beschreiben oder nicht. Beachten Sie, dass die Anordnung der Ja/Nein-Kästchen unterschiedlich sein können.

Beurteilungsbogen 2 enthält Skalen, auf denen Sie differenzierter entscheiden sollen, inwieweit die Empfindungsbeschreibungen auf die einzelnen Schwingungsdarbietungen zutreffen oder nicht.

Beurteilungsbogen 3 enthält wieder Begriffe, bei denen Sie entscheiden sollen, ob diese Ihre Empfindungen beschreiben oder nicht. Bitte wundern Sie sich nicht, wenn Sie Begriffe aus dem Beurteilungsbogen 1 wiedererkennen. Wir möchten nur wissen, ob sich nach dem ersten Versuchsteil Ihre Eindrücke vielleicht geändert haben.

Abschließendes Gespräch
Abschließend möchten wir gerne von Ihnen wissen, wie es Ihnen bei dem Versuch gegangen ist. Sie können alles, was Ihnen dabei durch den Kopf geht zur Sprache bringen. Wir sind umfassend an Ihren Wahrnehmungen der Ganzkörperschwingungen interessiert.

In diesem Gespräch werden von unserer Seite noch ein paar versuchsorganisatorische Dinge geklärt. Damit wird dieser Versuch für Sie beendet sein. Er dauert insgesamt etwa 60 Minuten.

Bitte beachten Sie während die Plattform schwingt, dass

- Sie sich möglichst wenig bewegen,
- Ihre Füße flach auf dem Gitter aufgestellt sind und
- Ihre Hände locker auf den Beinen aufliegen.

Herzlichen Dank für Ihre Teilnahme!

Versuchsleiterin: Alice Hoffmann

Figure .4.: Instruction sheet for the first measurement date of a proband. The instructions for the second date was similar. Only the order of the parts of the experiment changed

Signal 1 Beurteilungsbogen 1 Session 1

Beschreiben die folgenden Begriffe ihre Wahrnehmung?

Schwabbeln
Ja θ Nein θ

Unangenehm
Nein θ Ja θ

Schwanken
Ja θ Nein θ

Kribbeln
Ja θ Nein θ

Schwingen
Nein θ Ja θ

Schaukeln
Ja θ Nein θ

Holpern
Nein θ Ja θ

Schütteln
Nein θ Ja θ

Wackeln
Ja θ Nein θ

Unruhig
Nein θ Ja θ

Rau
Ja θ Nein θ

Vibrieren
Nein θ Ja θ

Seegang
Nein θ Ja θ

Holperpiste
Ja θ Nein θ

Kopfsteinpflaster
Nein θ Ja θ

Schüttern
Ja θ Nein θ

Wippen

Nein θ Ja θ

Zittern
Ja θ Nein θ

Flimmern
Ja θ Nein θ

Prickeln
Nein θ Ja θ

Kippeln
Nein θ Ja θ

Wanken
Ja θ Nein θ

Beben
Ja θ Nein θ

Schlottern
Nein θ Ja θ

Rattern
Ja θ Nein θ

Pendeln
Nein θ Ja θ

Schlingern
Nein θ Ja θ

Wogen
Ja θ Nein θ

Wiegen
Ja θ Nein θ

Schunkeln
Nein θ Ja θ

Kitzeln
Ja θ Nein θ

Signal............................ Proband............................ Datum................................

Figure .5.: Semantic differential with 31 words used in experiment "Analysing perceptual dimensions with a semantic differential"

Signal 1 Beurteilungsbogen 2 Session 1

In wie weit lässt sich ihre Wahrnehmung durch die folgenden Begriffe beschreiben?

		1	2	3	4	5	6	7	
Schwabbeln	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Zittern	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Schwankend	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Kribbeln	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Schwingen	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Schaukeln	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Holpern	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Schütteln	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Wackeln	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Unruhig	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Rau	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Vibrieren	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Schüttern	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Holperpiste	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Prickeln	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Wippen	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu
Flimmern	trifft nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft zu
Kopfsteinpflaster	trifft zu	☐	☐	☐	☐	☐	☐	☐	trifft nicht zu

Signal.......................... Proband.......................... Datum..........................

Figure .6.: Semantic differential with 18 words used in experiment “Analysing perceptual dimensions with a semantic differential”

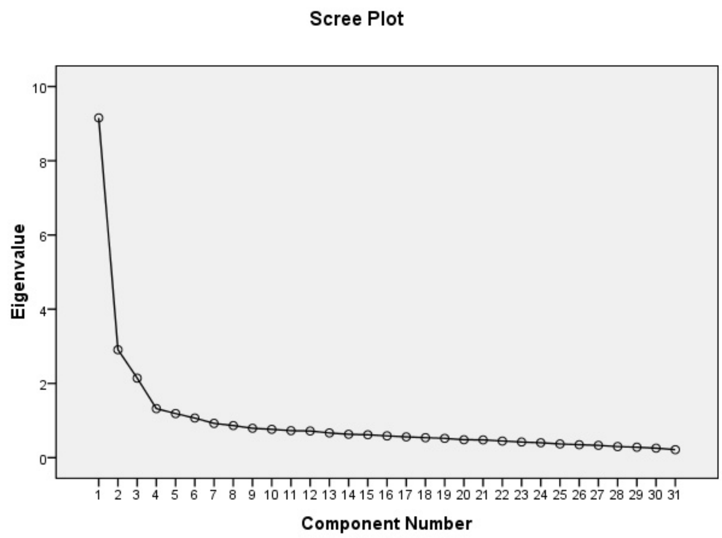

Figure .7.: Screeplot for the factor analysis over the results of the semantic differential with 31 items

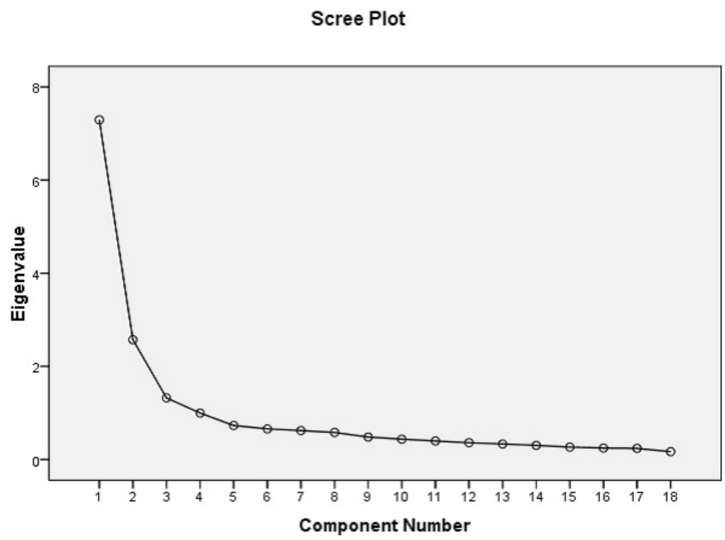

Figure .8.: Screeplot for the factor analysis over the results of the semantic differential with 18 items

Table .3.: Table of the mean values and standard deviations (STDV) of the answeres to the semantic differential with 31 words

	Frequenz	4		8		12		20		25		40	
		Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
1.Faktor	schaukeln	0,6267	0,4869	0,3333	0,4746	0,0667	0,2511	0,0133	0,1155	0,0133	0,1155	0,0133	0,1155
	wogen	0,5067	0,5033	0,1467	0,3562	0,0533	0,2262	0,0533	0,2262	0,0133	0,1155	0,0133	0,1155
	wanken	0,6400	0,4832	0,3067	0,4642	0,0667	0,2511	0,0000	0,0000	0,0000	0,0000	0,0133	0,1155
	pendeln	0,5067	0,5033	0,1200	0,3271	0,0533	0,2262	0,0267	0,1622	0,0267	0,1622	0,0133	0,1155
	schwanken	0,5067	0,5033	0,3067	0,4642	0,1067	0,3108	0,0133	0,1155	0,0133	0,1155	0,0000	0,0000
	Seegang	0,5200	0,5030	0,1600	0,3691	0,0267	0,1622	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
	schunkeln	0,4667	0,5022	0,2800	0,4520	0,0800	0,2731	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
	wiegen	0,3733	0,4869	0,0800	0,2731	0,0133	0,1155	0,0267	0,1622	0,0133	0,1155	0,0267	0,1622
	wippen	0,7467	0,4378	0,4667	0,5022	0,1333	0,3422	0,0667	0,2511	0,0267	0,1622	0,0267	0,1622
	kippeln	0,4000	0,4932	0,2933	0,4584	0,1333	0,3422	0,1200	0,3271	0,0667	0,2511	0,0533	0,2262
	wackeln	0,7867	0,4124	0,6933	0,4642	0,4533	0,5012	0,1867	0,3923	0,1867	0,3923	0,1067	0,3108
	schlingern	0,4133	0,4957	0,3600	0,4832	0,1733	0,3811	0,0267	0,1622	0,0000	0,0000	0,0000	0,0000
	schwingen	0,7867	0,4124	0,6400	0,4832	0,4533	0,5012	0,3067	0,4642	0,2267	0,4215	0,1733	0,3811
2.Faktor	prickeln	0,0000	0,0000	0,1333	0,3422	0,2533	0,4378	0,6133	0,4903	0,6667	0,4746	0,7467	0,4378
	kribbeln	0,0267	0,1622	0,1467	0,3562	0,5067	0,5033	0,7600	0,4300	0,8000	0,4027	0,8667	0,3422
	flimmern	0,0267	0,1622	0,0533	0,2262	0,3067	0,4642	0,4667	0,5022	0,5467	0,5012	0,7333	0,4452
	kitzeln	0,0133	0,1155	0,0667	0,2511	0,3067	0,4642	0,5600	0,4997	0,5733	0,4979	0,6800	0,4696
	zittern	0,0267	0,1622	0,2667	0,4452	0,6667	0,4746	0,8267	0,3811	0,8533	0,3562	0,8933	0,3108
	vibrieren	0,0267	0,1622	0,2533	0,4378	0,8667	0,3422	0,9467	0,2262	0,9600	0,1973	0,9867	0,1155
	schwabbeln	0,8667	0,3422	0,7467	0,4378	0,4933	0,5033	0,2000	0,4027	0,0533	0,2262	0,0133	0,1155
	rattern	0,0800	0,2731	0,3733	0,4869	0,6267	0,4869	0,6800	0,4696	0,6933	0,4642	0,6000	0,4932
	holpern	0,6533	0,4791	0,7733	0,4215	0,6000	0,4932	0,2800	0,4520	0,1600	0,3691	0,0800	0,2731
	Holperpiste	0,5867	0,4957	0,6667	0,4746	0,4400	0,4997	0,2133	0,4124	0,1067	0,3108	0,0800	0,2731
3.Faktor	schtteln	0,5600	0,4997	0,8000	0,4027	0,7600	0,4300	0,6267	0,4869	0,5467	0,5012	0,3600	0,4832
	schlottern	0,1733	0,3811	0,5333	0,5022	0,6267	0,4869	0,4800	0,5030	0,4533	0,5012	0,3200	0,4696
	schttern	0,1733	0,3811	0,3600	0,4832	0,5867	0,4957	0,4133	0,4957	0,4800	0,5030	0,3733	0,4869
	Kopfsteinpflaster	0,4133	0,4957	0,6000	0,4932	0,3733	0,4869	0,2400	0,4300	0,2000	0,4027	0,0667	0,2511
4.Faktor	unangenehm	0,2667	0,4452	0,4400	0,4997	0,4000	0,4932	0,2267	0,4215	0,2400	0,4300	0,1467	0,3562
	unruhig	0,4933	0,5033	0,6933	0,4642	0,6533	0,4791	0,6000	0,4932	0,5867	0,4957	0,4400	0,4997
	rau	0,0400	0,1973	0,2000	0,4027	0,4133	0,4957	0,4933	0,5033	0,6000	0,4932	0,5733	0,4979
5.Faktor	beben	0,4400	0,4997	0,5733	0,4979	0,4933	0,5033	0,4400	0,4997	0,3333	0,4746	0,3333	0,4746

Table .4.: Table of the mean values and standard deviations (STDV) of the answeres to the semantic differential with 31 words and a stronger criterium for the analysis (three times yes equals one, three times no eqals minus one and all in between is set to zero)

Frequenz	Schwabbeln	Unangenehm	Schwanken	Kribbeln	Schwingen	Schaukeln	Holpern	Schtteln	Wackeln
4	0,64	-0,52	0,08	-0,92	0,52	0,2	0,28	0,12	0,52
8	0,36	-0,16	-0,4	-0,6	0,28	-0,28	0,52	0,52	0,32
12	0	-0,08	-0,72	0	-0,04	-0,84	0,2	0,48	-0,08
20	-0,56	-0,48	-0,96	0,44	-0,32	-0,96	-0,36	0,24	-0,56
25	-0,84	-0,52	-0,96	0,6	-0,48	-0,96	-0,64	0,12	-0,48
40	-0,96	-0,68	-1	0,68	-0,6	-0,96	-0,8	-0,24	-0,8

Frequenz	Unruhig	Rau	Vibrieren	Seegang	Holperpiste	Kopfsteinpflaster	Schttern	Wippen	Zittern
4	0	-0,92	-0,92	0	0,16	-0,24	-0,56	0,44	-0,92
8	0,36	-0,56	-0,44	-0,64	0,28	0,2	-0,2	-0,08	-0,4
12	0,24	-0,16	0,64	-0,96	-0,08	-0,32	0,16	-0,72	0,28
20	0,16	-0,04	0,84	-1	-0,48	-0,48	-0,16	-0,8	0,56
25	0,12	0,24	0,88	-1	-0,76	-0,6	-0,08	-0,92	0,64
40	-0,08	0,2	0,96	-1	-0,76	-0,84	-0,16	-0,92	0,76

Frequenz	Flimmern	Prickeln	Kippeln	Wanken	Beben	Schlottern	Rattern	Pendeln	Schlingern
4	-0,92	-1	-0,16	0,24	-0,12	-0,6	-0,8	0	-0,16
8	-0,88	-0,68	-0,36	-0,32	0,08	0	-0,2	-0,76	-0,24
12	-0,32	-0,52	-0,64	-0,84	0,08	0,2	0,2	-0,88	-0,6
20	-0,04	0,16	-0,72	-1	-0,16	-0,12	0,28	-0,96	-0,92
25	0	0,2	-0,84	-1	-0,28	-0,12	0,4	-0,96	-1
40	0,4	0,48	-0,88	-0,96	-0,28	-0,36	0,28	-0,96	-1

Frequenz	Wogen	Wiegen	Schunkeln	Kitzeln
4	-0,04	-0,2	-0,04	-0,96
8	-0,68	-0,8	-0,32	-0,84
12	-0,88	-0,96	-0,8	-0,4
20	-0,88	-0,96	-1	0,04
25	-0,96	-0,96	-1	0,16
40	-0,96	-0,96	-1	0,28

Table .5.: Table of the mean values and standard deviations (STDV) of the answeres to the semantic differential with 18 words

	Frequenz	4		8		12		20		25		40	
		Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
1.Faktor	Schaukeln	3,253	1,946	4,280	1,956	5,840	1,452	6,253	1,231	6,613	0,769	6,667	0,811
	Schwankend	3,093	1,772	4,227	2,096	5,520	1,750	6,173	1,309	6,280	1,203	6,533	1,288
	Wippen	2,853	1,821	3,787	2,081	5,360	1,682	6,253	1,128	6,187	1,227	6,467	0,991
	Wackeln	2,853	1,698	3,427	1,795	4,693	1,952	5,080	1,930	5,480	1,663	5,867	1,639
	Schwingen	2,667	1,855	3,627	1,916	4,880	1,867	5,360	1,591	5,653	1,573	5,973	1,442
	Schwabbeln	2,053	1,584	2,480	1,622	4,587	2,027	5,787	1,613	6,173	1,212	6,680	0,619
2.Faktor	Prickeln	6,653	0,726	5,880	1,479	4,733	1,954	3,347	2,063	3,013	1,928	2,840	2,020
	Kribbeln	6,547	0,905	5,587	1,748	3,920	2,045	2,707	1,887	2,600	1,724	2,227	1,673
	Zittern	6,587	0,856	5,013	1,878	3,333	1,975	2,640	1,698	2,080	1,431	2,480	1,877
	Flimmern	6,373	1,239	5,720	1,615	4,653	2,050	3,640	2,051	3,200	2,073	2,867	2,009
	Vibrieren	6,147	1,216	4,733	1,905	2,880	1,627	2,107	1,448	1,653	1,121	1,547	1,244
	Schttern	5,133	1,758	4,027	1,910	3,920	1,894	4,040	1,913	3,973	1,874	4,467	1,862
	Rau	6,360	0,981	5,253	1,725	4,360	2,084	3,827	2,146	3,800	2,254	3,893	2,147
3.Faktor	Holpern	3,347	1,935	2,707	1,600	3,867	1,905	5,053	1,895	5,373	1,792	5,800	1,636
	Holperpiste	3,413	2,047	2,635	1,779	4,173	2,049	5,160	2,034	5,827	1,571	6,040	1,528
	Kopfsteinpflaster	4,160	2,260	3,107	1,886	4,333	2,082	5,053	2,137	5,333	2,062	5,827	1,571
	Unruhig	4,120	2,000	3,307	2,000	3,493	2,029	4,027	2,212	3,480	2,088	4,253	2,138
	Schtteln	4,080	1,978	3,507	1,841	3,200	1,685	4,560	1,974	4,093	2,170	4,813	2,025

VP	Height	Weight	Age	BMI	gender	factors 31 items	factors 18 items
AK	180	110	20	33,95	m	4	3
AS	168	60	20	21,26	f	6	1
AW	176	100	25	32,28	f	3	2
BS	157	54	22	21,91	f	4	2
CIS	168	58	21	20,55	f	2	6
CS	196	110	22	28,63	m	2	3
DiW	182	68	30	20,53	m	4	2
DW	170	62	27	21,45	f	2	1
EE	181	63	20	19,23	m	1	6
FD	170	65	20	22,49	f	5	1
FV	175	71	36	23,18	m	1	7
JG	183	92	20	27,47	m	3	1
JK	174	66	20	21,80	f	2	2
KS	160	52	25	20,31	f	3	4
LH	175	68	25	22,20	f	1	1
LP	170	68	20	23,53	f	3	1
MKH	182	86	26	25,96	m	1	4
MW	182	67	21	20,23	m	4	3
RP	168	66	19	23,38	f	1	3
SH	179	65	32	20,29	m	7	4
SiS	178	63	25	19,88	m	2	5
StS	189	83	20	23,24	m	1	3
TS	190	75	21	20,78	m	5	5
UL	178	78	26	24,62	m	2	1
VS	168	75	19	26,57	f	3	1

Table .6.: Comparison of the results of the factor analyses over the probands for the semantic differentials with 31 and 18 items to known facts about the probands