Signal Detection Theory: Psychoacoustic Measuring Methods

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Synopsis:

This report covers different signal detection methods and describes the advantages and disadvantages and how to compare results from different methods.

Real and computer simulated experiments based on these methods, took place and their efficiency as tools to investigate the auditory processing and perception of humans are discussed.

Main conclusion were:

- The method of constant stimuli is a useful method to estimate roughly the psychometric function in a relatively short period of time.
- The transformed up-down methods are used to measure precisely the threshold at different points of the psychometric functions.
- The PEST method is used to measure the threshold at the 50% point of the psychometric function with a minimum number of presentations.

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Introduction

Signal Detection Theory (often referred to as SDT) is used to describe and analyze decisions that are made in uncertain or ambiguous situations. SDT theory is used widely in areas related to psychophysics, and features the basis of psychoacoustic measurements. Different signal detection models have been developed throughout the last decades and the aim of this laboratory exercise is to investigate some of them. The theoretical background for three different psychoacoustic measurement methods (constant stimuli method, transformed up-down method and Parameter Estimation by Sequential Testing) is described and the advantages and disadvantages are discussed. Real and computer simulated psychoacoustic experiments based on the above methods took place and conclusions concerning their efficiency were extracted.

For each method, the dependence of the results and their dispersion have been analyzed as a function of the modification of the parameters using both human test subjects and computer models.

Technical University of Denmark, March 6, 2008

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Chapter 1

Theory

1.1 Psychometric functions

When doing masking measurements as investigated in this report, results can be expected to be psychometric functions, see figure 1.1.

![Psychometric function](image)

Figure 1.1: Psychometric function. The measuring parameter in this report is the level of test signal measured (pure tone and probe respectively) in dB$_{SPL}$. The dotted lines indicate where the levels corresponding to the 50 %, the 70.7 % and the 79.4 % points can be read from the figure.

The results of a 1-up 3-down measurements method correspond to 79.4 % points on the psychometric function. This means that the thresholds found by the method, describe when the probability that a test subject will give the correct answer is 79.4 %. By using a 1-up, 2-down measurements procedure the results correspond to 70.7 % points on the psychometric function. [Dau, 2008, p. 4]

The psychometric function covers the range from 0 % correct to 100 % correct. But
that depends on the method used for the measurements. If the measurement method uses the Alternative Forced Choice (AFC) procedure, is it possible to guess the correct answer even though the test subject can not hear which interval contains the correct one. (See 2.1.2 on page 10 for a description of the AFC procedure.) This results in a change of the psychometric function. I.e. if a 2-AFC is used the lowest possible value of the psychometric function is 50% because there is always 50% chance of guessing correct even though the masked tone is not heard. By using a 3-AFC the lowest possible value of the psychometric function is 33% and so on, see figure 1.2.

![Figure 1.2: Theoretic psychometric functions, calculated from different AFC procedures. It is easy to see that the more alternative choices, the less influence luck will have on the psychometric function.](image)

It is not possible just to compare psychometric functions if they are made by different methods. In this exercise the method of constant stimuli and a transformed up-down method are used. To compare the results from two different methods, one must calculate the probability of getting a correct answer for each method.

When using the method of constant stimuli, either the test subject heard the pure tone to look for or not, for more details see section 1.2. When using an AFC procedure the test subject has a possibility of making a false positive, meaning the test subject chose the correct interval by guessing even though the test subject had not heard the tone, see figure 1.3.

From figure 1.3 an equation for the probability of choosing the correct interval using AFC can be made. The equation becomes:

\[ P(AFC) = P^* + (1 - P^*) \cdot \frac{1}{n} \]  

(1.1)

In the first term the test subject has either heard the pure tone to look for or not.
Chapter 1. Theory

Figure 1.3: Probability of choosing the correct interval using AFC.

is a probability of $P^*$ that the test subject has heard the tone and a probability of $1 - P^*$ that the test subject has not heard the tone. The second term describes the probability of the test subject choosing the correct interval by mistake.

Calculating which point on the psychometric function a given AFC procedure corresponds to, for a psychometric function based on a true/false method (heard the tone/did not hear the tone method like the method of constant stimuli) can be done using equation (1.1).

$$P(AFC) = P^* + (1 - P^*) \cdot \frac{1}{n}$$

$$n \cdot P(AFC) = n \cdot P^* + (1 - P^*)$$

$$n \cdot P(AFC) - 1 = P^*(n - 1)$$

$$\frac{n \cdot P(AFC) - 1}{n - 1} = P^*$$

(1.2)

1.2 Method of constant stimuli

The method of constant stimuli rely on a good experimenter. Before the test starts the experimenter has to choose a likely level range where he/she expects the threshold to be and the levels will maintain their value throughout the experiment, hence the name 'constant stimuli’. Each of the levels is presented the same number of times and presentation levels are randomly distributed over this level range before the experiment starts. After each presentation the test subject indicates whether the signal is audible or not. At the end of the experiment the percent correct scores will be calculated for each presentation level. Plotting the percent correct responses against the presentation level gives a coarse approximation of the psychometric function. [Poulsen, 2005b, p. 15]

Figure 1.4 shows an example of a threshold determination using the method of constant stimuli.
Chapter 1. Theory

Technical University of Denmark

stimuli. The presentation levels are indicated relative to the expected threshold and each level is presented three times in the example.

![Figure 1.4: Sequence of presentation levels and corresponding responses in the method of constant stimuli. A positive response is marked by a plus, and a negative response is marked by a circle. From [Poulsen, 2005b, p. 15].](image)

As seen on figure 1.4, the levels are presented in random order and with 2 dB between the levels. The number of positive responses are counted for each presentation level and a coarse approximation to the psychometric function is obtained as seen on figure 1.5.

![Figure 1.5: Psychometric function for the example in figure 1.4. The threshold can then be determined from the curve. The solid line is a fitting of the responses from the test subject and the dotted line is the actual responses. From [Poulsen, 2005b, p. 16].](image)

The psychometric function is not always as monotonic as the one shown on figure 1.5. Experience shows that the threshold can be determined by means of a straight line drawn...
from the endpoints of the uncertainty range, where the uncertainty range is defined as the highest relative level [dB] with 0 % positive responses to the lowest relative level [dB] with 100 % positive responses. In figure 1.5 the uncertainty range is from -4 dB to 2 dB.

To obtain a more precise psychometric function the number of repetitions of each level can be increased. Likewise more levels can be chosen to cover a broader range of the psychometric function. But increasing the number of levels and/or the number of repetitions before the test will result in an increase in measurement time and may tire the test subject, risking a change in threshold. This is a problem because the method of constant stimuli relies on a constant threshold during the whole measurement. [Poulsen, 2005b, p. 16]

A possibility to increase the level range, and thereby lower the importance of a correct threshold estimate from the experimenter, is to increase the presentation level step size at the expense of lower resolution. It is seldom possible to cover a 0 % to 100 % response range with a given level range for all test subjects. Especially in balance measurement it is a problem if the measurement range is far from being symmetrical around the threshold. In such a situation there will be many more responses of a certain kind. Whether there will be most positive or negative depends on whether the expected threshold is higher or lower than the actual threshold for the given test subject. When there are many more responses of a certain kind this may influence the test subject to change his/her opinion. Typically the threshold is moved towards the middle of the presentation range. The phenomenon is called ’central adaption’ and is obviously unwanted since the results will not match the actual threshold for the given test subject. [Poulsen, 2005b, p. 16]

Often when using the method of constant stimuli the experimenter will make a few initial measurements with each test subject in order to get a coarse idea about where the threshold is. [Poulsen, 2005b, p. 16]

1.3 Transformed up-down method

The transformed up-down method is an adaptive measuring procedure. The stimuli levels in any trail are determined by the preceding stimuli and responses.

The experimenter has to choose the increment by which the stimulus is either increased or decreased (the step size) and the number of reversals after which the procedure will be terminated. In principle the same step size is used throughout the measurement, but often the step size will decrease after a chosen number of reversals in order to give a more
precise result of the point of interest on the psychometric function.

The procedure should start with a presentation level where the subjects can clearly detect the stimulus. The following presentation levels are determined by the following for the up-down method used.
E.g. for a 1-up, 2-down method the rules are:

- After each negative response (or no response) the level is increased by the step size.
- After two successive positive response (detection) the level is decreased by the step size.

The procedure stops after a certain number of changes from positive to negative response and vice versa (the reversals). The result of the measurement (the threshold) is the average of the levels at the reversals. This means that transformed up-down methods only give one result corresponding to the threshold for a certain point on the psychometric function. An 1-up 1-down method results at a 50 % point, an 1-up 2-down procedure gives the threshold on the 70.7 % point and so on.

The one-up two-down method used in this report is a strategy, where (as the name indicates) the level of the test tone is decreased after three consecutive correct responses, but increased after only one incorrect answer and results in a 70.7 % point on the psychometric function. [Dau, 2008, p. 4]

By using adaptive methods, like the transformed up-down method, it is possible to concentrate the presentation within the most interesting area, i.e. around the point on the psychometric function that is of interest. In this way adaptive methods are faster because no time is wasted by presenting levels which are of no interest.

1.4 Parameter estimation by sequential testing

Parameter Estimation by Sequential Testing method (often referred as PEST) is an efficient psychophysical method that was developed by Taylor and Creelman [Taylor and Creelman, 1967] at the end of the sixties and became very popular because of its efficiency. The principles in the PEST method are:

1. The presentation level is kept at a fixed level for a number of presentations.

2. For each presentation the number of positive responses is compared to the number of positive responses one would expect if the presentation level was exactly at the threshold.
In as few trials as possible the PEST method decides whether the testing level is above or below of the target point on the psychometric function. In contrast to the classical up-down method, the PEST method uses different step-sizes. Big steps are used in the beginning of a measurement and they become smaller afterwards. A minimum step size is used as stop criterion. In order to explain the procedure that PEST method uses, an example is given.

Suppose that four presentations of the same level are presented to the test subject. The subject can give a positive or a negative answer. Three of the presentations have given a positive response, i.e. $N(C) = 3$. If the probability on the psychometric function is chosen as $P = 0.5$, it must be expected that the number of positive responses would be $P \times T$ where $T$ is the number of responses. In this example the expected number of positive responses would be $0.5 \times 4 = 2$, but instead the test subject gave 3 positive responses. There are thus more positive responses, $N(C)$, than what is expected by the probabilistic function $P = 0.5$. Therefore the presentation level is assumed to be above the threshold and the next presentation levels should be decreased. One of the PEST rules says that the presentation level shall be kept constant as long as $N(C)$ is within the limits of $(P \times T) \pm W$ where $W$ is a so called Wald sequential likelihood-ratio test. Often a value of $W = 1$ or $W = 1.5$ is used. The PEST rule says that the level shall be changed if $N(C)$ is equal to or exceeds one of these limits. If the upper limit is reached the level shall be decreased. If the lower limit is reached the level shall be increased.

Compared to the classical methods the PEST method gives a reduction in the number of presentations by assuming an expected threshold. The efficiency of PEST is almost independent of conditions and the estimate is also unbiased; with some minor exceptions. In sum PEST proved to be very efficient, flexible, useful with naive or trained observers, robust and easy to run at the time that it was developed. [Taylor and Creelman, 1967, p. 783]
2.1 Measuring setup

2.1.1 List of equipment

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>DTU number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sennheiser HDA 200</td>
<td>Headphone</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>Limiter for HDA 200</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>Computer with soundcard</td>
<td>–</td>
</tr>
<tr>
<td>Matlab 2006b</td>
<td>Software with measuring procedure</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 2.1: Table of equipment used in the experiment.

2.1.2 Measuring procedure

The measuring setup is shown in figure 2.1. The test subjects are tested using a computer running pre-programmed Matlab procedures.

The sound card of the computer is hooked up to a pair of HDA200 headphones through a limiter to protect the ears of the test subjects. The Matlab procedure uses the responses given by the test subjects to decide what the next test signal will be.

The measuring procedure used to test three test subjects for this report uses several procedures: The method of constant stimuli and a Three Alternative Forced Choice (3-AFC) one-up two-down method [Dau, 2008, p. 7]. The 3-AFC procedure implies that the test subject is presented to sequences of three signals separated by pauses. The test sequence is three noise signals separated by a pause, where one of the signals also carries a pure tone of 1 kHz and the other is just noise. The test subject is asked to indicate which of the three signals carries the tone. An example on such a test sequence with two alternatives
Chapter 2. Measuring methods

Technical University of Denmark

Figure 2.1: Measuring setup used for this report. The sound card of the computer is hooked up to a pair of HDA200 headphones through a limiter to protect the ears of the test subjects.

is given in figure 2.2, where the second signal is the carrier of the pure tone.

Figure 2.2: Presentation sequence of a two alternative forced choice procedure. From [Poulsen, 2005a, p. 3].

The task of each of the measurements in this report is to detect a 1 kHz tone consisting of 500 ms with Hanning ramps of 5 ms. The noise is a bandlimited Gaussian noise with bandwidth of 1 octave and geometric center frequency of 1 kHz presented at 65 dB$_{extSPL}$, with duration of 500 ms with Hanning ramps of 5 ms. [Dau, 2008, p. 6]

The cut-off frequencies of the noise are:

\[
f_u = \sqrt{2} \cdot 1000 = 1414\text{Hz}
\]

\[
f_l = \frac{1}{\sqrt{2}} \cdot 1000 = 707\text{Hz}
\]

This exercise uses a 3-AFC procedure with a transformed 1-up 2-down procedure and the method of constant stimuli. To compare the results from the two different methods, equation (1.2), page 3 then becomes:

\[
\frac{3 \cdot 0.707 - 1}{3 - 1} = 0.56
\]

Equation (2.3) shows that the value [dB SPL] for the 70.7 % on the psychometric function for a 3-AFC method using 1-up 2-down is equal to the value [dB SPL] for the 56 % point on the psychometric function for the method of constant stimuli as shown on figure 2.3. In reality the values [dB SPL] will not be exactly the same (as shown in figure 2.3) because there are many factors that influence the psychometric function of humans. E.g. these factors can be lack of concentration, tiredness, background noise etc.
February 2008

Chapter 2. Measuring methods

2.2 Measurements using a computer model

Psychoacoustic measurements can be very time consuming. For this reason computer models are used, in order to simulate them and evaluate the effect of different parameters of the method in the accuracy of the results and their repetitiveness. The algorithm that is applied in those models includes the following steps:

1. Generation of a random number \( x \) between 0 and 1.

2. Comparison of number \( x \) with the values of the psychometric function of the model, \( p(L) \), where \( L \) is the level, and selection of the interval containing the signal, when \( x < p(L) \), or a random interval that does not contain the signal when \( x \geq p(L) \).

The above procedure can lead to fixed psychometric functions, which can serve many different purposes and can prove to be very useful for several applications, although they are not realistic. There is a very high possibility that the psychometric function will not be the same for different humans, since elements like the ‘criterion’ can affect their shape. Additionally, the psychometric function for the same test subject can prove to be different under some circumstances, like tiredness, lack of concentration etc.

A computer model can give a great understanding of the way the different signal detection theories function. By modifying certain parameters, like the number of the levels presented, the number of intervals, the step size, repetitions of the sounds, it can be seen how those parameters affect the shape of the psychometric function. In this exercise computer models were used in order to visualize the prediction of the psychometric function.

Figure 2.3: Equation (2.3) shows that the value [dB SPL] for the 70.7 % on the psychometric function for a 3-AFC method using 1-up 2-down (dotted line) is equal to the value [dB SPL] for the 56 % point on the psychometric function for the method of constant stimuli (straight line).
using the method of constant stimuli, the transformed up-down method and the PEST method while modifying various parameters.

In the following lines, a list of the performed tests with the computer models is given.

- Constant stimuli method using presentation levels from 51 to 60 dB with one dB steps
  - 3 runs with 10 repetitions
  - 3 runs with 20 repetitions
  - 3 runs with 30 repetitions

- Transformed up-down methods
  - 2 runs with one-up two-down, 3-AFC procedure, 1 dB resolution and 8 reversals
  - 1 run with one-up two-down, 5-AFC procedure, 1 dB resolution and 8 reversals
  - 2 runs with one-up two-down, 10-AFC procedure, 1 dB resolution and 8 reversals
  - 1 run with one-up two-down, 3-AFC procedure, 0.5 dB resolution and 16 reversals
  - 1 run with one-up two-down, 3-AFC procedure, 0.5 dB resolution and 16 reversals

- PEST method
  - 4 runs with $W=1$
  - 4 runs with $W=1.5$
  - 2 runs with $W=2$
Chapter 3

Results

3.1 Method of constant stimuli

The method of constant stimuli was used to obtain data about the detection probability for a 1 kHz pure tone at different levels in background noise (Gaussian distribution, 65 dB SPL, one octave bandwidth) for three test subjects. A first trial was performed for each one and the threshold was estimated to lay between 55 and 65 dB.

The presentation levels for all the test subjects were [40 44 47 50 54 56 58 61 65] dB. Each level was presented 10 times, in random interleaving. The percent of correct responses (corresponding to the detection of the tone) for the test subjects EG, DP and TL are presented in figures 3.1, 3.2 and 3.3, respectively.

The same test was performed by a computer model, described in section 2.2. In this case, the scope of the test was to evaluate the effect of the number of repetitions in the accuracy of the results. Therefore, the results of three trials for the same test using 10 repetitions for each presentation level, 20 and 30 are presented in figures 3.4, 3.5 and 3.6, respectively.

The threshold corresponding to the 50% point of the psychometric function and the standard deviation of the obtained values for the different trials in each test, averaged over the different presentation levels are shown in table 3.1 on page 17.
Figure 3.1: Percent of correct responses detecting a 1 kHz tone in background noise at different presentation levels for test subject EG, and fitted psychometric function according to these points using the fitting type described on [Dau, 2008, p.8].

Figure 3.2: Percent of correct responses detecting a 1 kHz tone in background noise at different presentation levels for test subject DP, and fitted psychometric function according to these points using the fitting type described on [Dau, 2008, p.8].
Figure 3.3: Percent of correct responses detecting a 1 kHz tone in background noise at different presentation levels for test subject TL, and fitted psychometric function according to these points using the fitting type described on [Dau, 2008, p.8].

Figure 3.4: Percent of correct responses detecting a 1 kHz tone in background noise at different presentation levels using the computer model, each point corresponding to 10 presentations.
Figure 3.5: Percent of correct responses detecting a 1 kHz tone in background noise at different presentation levels using the computer model, each point corresponding to 20 presentations.

Figure 3.6: Percent of correct responses detecting a 1 kHz tone in background noise at different presentation levels using the computer model, each point corresponding to 30 presentations.
### Chapter 3. Results

<table>
<thead>
<tr>
<th>Standard deviation</th>
<th>Threshold [dB SPL] (50 % point)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Run 1</td>
</tr>
<tr>
<td>10 presentations</td>
<td>12.9</td>
</tr>
<tr>
<td>20 presentations</td>
<td>7.1</td>
</tr>
<tr>
<td>30 presentations</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Table 3.1: Calculated threshold for different number of presentation repetitions with the method of constant stimuli, using a computer model. The standard deviation of the values obtained in different trials, for different number of presentation repetitions, is averaged over the presentation levels. * The threshold is at the 50 % point on the psychometric function.

#### 3.2 Transformed up-down method

The determination of the signal detection threshold was determined also by means of an one-up two-down method, where each presentation was a 3AFC procedure. The results corresponding to the three human test subjects are presented in table 3.2.

<table>
<thead>
<tr>
<th>Test subject</th>
<th>Threshold [dB SPL] (70.7 % point)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Run 1</td>
</tr>
<tr>
<td>TL</td>
<td>53.4</td>
</tr>
<tr>
<td>DP</td>
<td>59.1</td>
</tr>
<tr>
<td>EG</td>
<td>58.8</td>
</tr>
</tbody>
</table>

Table 3.2: Calculated threshold for test subjects TL, DP and EG with the one-up two-down method. * The threshold is at the 70.7 % point on the psychometric function.

The test of the transformed up-down method was also completed by the computer model with different parameters. In table 3.3, the results obtained by averaging several runs with the same parameters are shown, for different number of alternative forced choices.

<table>
<thead>
<tr>
<th>N-AFC</th>
<th>Resolution [dB]</th>
<th>Reversals</th>
<th>Standard deviation [dB]</th>
<th>Threshold [dB] (70.7 % point)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>8</td>
<td>1.9</td>
<td>55.1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>8</td>
<td>1.4</td>
<td>56.1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>8</td>
<td>1.1</td>
<td>56.4</td>
</tr>
</tbody>
</table>

Table 3.3: Calculated threshold and standard deviation obtained by the one-up two-down method using the computer model. * The threshold is at the 70.7 % point on the psychometric function.

#### 3.3 PEST method

The test of the Parameter Estimation by Sequential Testing method was performed by the computer model with different parameters. In table 3.4, the results obtained by averaging
several runs with the same parameters are shown, for different values of the deviation limit $W$ of the Wald sequential likelihood ratio.

<table>
<thead>
<tr>
<th>Wald likelihood ratio</th>
<th>Number of presentations</th>
<th>Threshold [dB] (50 % point)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>55.2</td>
</tr>
<tr>
<td>1.5</td>
<td>44</td>
<td>54</td>
</tr>
<tr>
<td>2</td>
<td>74</td>
<td>54.5</td>
</tr>
</tbody>
</table>

Table 3.4: Calculated threshold and standard deviation obtained by the PEST method using the computer model. * The threshold is at the 50 % point on the psychometric function.
Discussion

According to the results presented in chapter 3, some points should be discussed.

4.1 Method of constant stimuli

Using the method of constant stimuli, only a rough estimation of the psychometric function for each test subject has been done in figures 3.1, 3.2 and 3.3, as there were only 10 presentations at each level. The test subjects faced difficulties to realize what they had to listen for. These functions have been estimated for individual data, because they are showing the detection probability for different test subjects. It does not make sense to fit one psychometric curve to the data of all the test subjects, because each of them has different criteria, hearing thresholds, mood and concentration. In figure 4.1 the fitted psychometric functions of the three subjects are shown whereas in table 4.1 the corresponding parameters of the curves are presented. There are remarkable differences in the slopes of the curves and this can be related to the different criteria of the test subjects. For example test subject DP gave a positive answer only when he was sure to have heard the tone and therefore the slope of the curve around the threshold is very steep. On the other hand EG had different criteria and EG would give a positive response even if she was not completely sure and the resulting curve is less steep.

<table>
<thead>
<tr>
<th>Test subject</th>
<th>Threshold [dB]</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL</td>
<td>54.5</td>
<td>7.31</td>
</tr>
<tr>
<td>DP</td>
<td>62.0</td>
<td>1.32</td>
</tr>
<tr>
<td>EG</td>
<td>53.9</td>
<td>13.2</td>
</tr>
</tbody>
</table>

Table 4.1: Calculated threshold at the 50% point of the psychometric function and σ parameter for the fitted curve computed with the constant stimuli method for test subjects TL, DP and EG.
Figure 4.1: Psychometric function corresponding to the 1 kHz tone detection in background noise for test subjects EG, DP and TL.

Using the computer model it is possible to appreciate the effects that modifications in the parameters produce in the results. In figures 3.4, 3.5 and 3.6 the results of the constant stimuli method for different number of repetitions are shown. It can be seen that the higher the number of repetitions the less dispersion of the data is observed and the fitted curves tend to converge. The standard deviation of the percent of correct responses is 12.9 for 10 presentations, 7.1 for 20 and 4.3 for 30 and the average threshold (50% point of the psychometric function), calculated with this method, is 55.2 dB SPL, as seen in table 3.1.

4.2 Transformed up-down method

Using the one-up two-down method the 70.7 % point on the psychometric function is determined. The psychometric function depends on the presentation procedure, so it is different for different number of alternative forced choices. For the case of three-intervals, three-AFC procedure, this theoretical curve presents a minimum value of 33.3 %, as it can be seen in figure 1.2.

In table 4.2 the calculated thresholds with the 1-up 2-down method and the 3-AFC procedure for the three test subjects are presented and compared to the results obtained with the CS method (50 % of the estimated psychometric functions). The points obtained with the
adaptive method should theoretically correspond to the 56 % point on the psychometric function, as demonstrated in section 1.3, but they provide different results. The deviations are likely to be due to the rough estimation of the psychometric function provided by the CS method and the fact that the threshold does not necessarily remain constant between two measurements in human persons (due to effects of tiredness, concentration, mood, etc.). It also be taken into account that it is easier to perform an up-down test, because the signal is presented at high levels and then lowered.

<table>
<thead>
<tr>
<th>Test subject</th>
<th>CS Threshold</th>
<th>AFC Threshold</th>
<th>P(%)</th>
<th>Theoretical Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL</td>
<td>54.5</td>
<td>53.7</td>
<td>45.3</td>
<td>56</td>
</tr>
<tr>
<td>DP</td>
<td>62.0</td>
<td>58.5</td>
<td>63.0</td>
<td>56</td>
</tr>
<tr>
<td>EG</td>
<td>53.9</td>
<td>58.4</td>
<td>0.3</td>
<td>56</td>
</tr>
</tbody>
</table>

Table 4.2: Comparison between the calculated thresholds with Constant Stimuli and AFC methods for test subjects TL, DP and EG. The points on the psychometric function of the CS method that the results of the 3-AFC correspond to are also calculated and compared to the theoretical ones.

Figure 4.2: Comparison of the calculated thresholds using the 1-up 2-down method with the psychometric functions calculated using the CS method and corresponding to different AFC procedures.

In figure 4.2 the psychometric function predicted by the computer model by using the CS method is modified to calculate the expected psychometric functions corresponding to different number of AFC. The calculated thresholds using the 1-up 2-down method are compared to the 70.7 % point of the psychometric functions. It can be seen that there some deviations between the obtained results and the expected ones. These results can
be observed also in figure 4.3. The calculated threshold with the 1-up 2-down method is higher the higher the number of AFC intervals.

![Figure 4.3: Calculated threshold with different AFC procedures](image)

### 4.3 PEST method

As the Wald likelihood ratio ($W$) is increased the number of presentation will increase rapidly as seen in table 4.4. This is because the higher the value of $W$, the more presentations are needed for $N(c)$ to exceed the limits ($P \times T \pm W$) before decreasing or increasing the level. This can be seen from equation 4.2.

\[
N(c) \times T < P \times T \pm W \tag{4.1}
\]
\[
\frac{N(c) \pm W}{P} \times T < T \tag{4.2}
\]

Where:
- $N(c)$ is the number of positive responses.
- $T$ is the number of responses.
- $P$ is the point on the psychometric function.
- $W$ is the Wald likelihood ratio.
Conclusion

In this laboratory exercise three different psychoacoustic measuring methods were studied to determine the detection threshold of a signal in background noise. This detection threshold can be described by a psychometric function, different for each test subject. Each method presents a series of advantages and disadvantages that allow to use them for different purposes. All tests have been performed by computer models in Matlab. Method of constant stimuli and the transformed up-down method were executed by real test subjects.

**The method of constant stimuli** is a useful method to estimate roughly the psychometric function in a relatively short period of time.

**The transformed up-down methods** are used to measure precisely the threshold at different points of the psychometric functions.

**The PEST method** is used to measure the threshold at the 50% point of the psychometric function with a minimum number of presentations.
Bibliography


Matlab code for AFCPsyFcn

```matlab
function p = AFCPsyFcn(x,mu,sigma,n)
% AFCPsyFcn Psychometric Function (according to n-AFC measurements)
% syntax: p = AFCPsyFcn(x,mu,sigma,n)
% Computes the psychometric function for an n-AFC measurements at point
% x. The psychometric function is calculated as a cumulative normal
% distribution described by its mean value mu and its standard
% deviation sigma.

p_cum = PsyFcn(x,mu,sigma);

p = p_cum + (1 - p_cum)/n;
```
