THRESHOLD DETECTION OF PULSE REPETITIONS AND SOUNDS FROM PULSE TO TONE

Bachelorproject

Jefta Saija, s1612727, jdsaija@ai.rug.nl
Supervisor: Tjeerd Andringa

Summary: Two studies have been conducted using experiments that let participants try to detect target sounds in pink noise. If they reported to have detected a target signal then next time the energy of the target signal of that condition is decreased by 1dB. If they reported not to have detected a target signal then next time the energy of the target signal of that condition is increased by 1dB. This results in data points around 50% probability of detecting a minimum of 1 target sound in the noise. One study examines the detection thresholds of pulse repetitions with irregular and regular intervals and the other the detection thresholds of target sounds between the pulse-domain and tone-domain. We expected that detection of thresholds in the first study is a statistical process in which the threshold detection value is a function of the number of repetitions and the standard deviation of noise in a Gaussian distribution. Hereby we aim to find the mean and especially the standard deviation. The difference of the mean and standard deviation between irregular and regular pulse intervals is small. The average mean therefore is -3.908 and the average standard deviation is 1.934. Also what has been found is a significant difference of 6 regular pulse repetitions being 0.78 dB lower than 6 irregular pulse repetitions. The second study gives us an indication of a transition point between the pulse-domain and the tone-domain. There has been found an indication of a transition point at a target sound with duration of 0.03 seconds.

1. Introduction

The problem how humans detect interesting sounds and how they distinguish these sounds from (background) noise is not yet solved. Andringa and Pals [1] studied how humans detect and recognize sounds. They studied the effect of priming and different strategies to detect and recognize environmental sounds. They hypothesized that being primed with a sound leads to a different kind of strategy for sound detection and recognition than without being primed with a sound. The strategy for detecting or recognizing a sound that is used without being primed is a (full) memory search for a matching sound class. If a listener has been primed with target sounds, then they already have an indication of what to expect in the near future and they only have to check if this expectation is present. This second strategy should account for lower detection and recognition thresholds.

The kind of priming used in their experiment is called perceptual priming. The participants (unconsciously) perceive stimuli and are (temporary) stored in implicit memory. This accounts for a faster detection and recognition of the stimuli in the near future [2].

To investigate if the hypothesis was correct, they performed an experiment with a number of participants. The participants were presented everyday sounds (target sounds) masked by noise. These target sounds consisted of sounds that were predominantly noise-like, pulse-like or tone-like. The aim was to find the detection and recognition thresholds by decreasing or increasing the decibel level of a target sound if the participant respectively did or did not detect or recognize the target sound. Figure 1 illustrates this process.

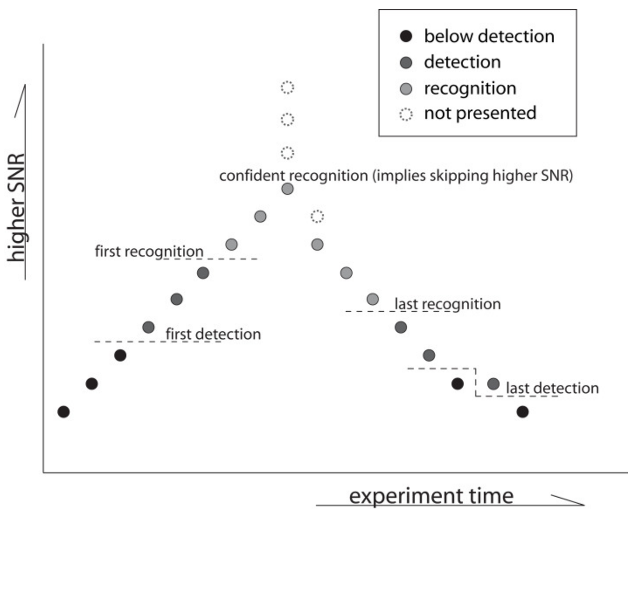

Figure 1 - Overview of the experimental design. The 10 different targets were presented in random alternating order. Each sound is first presented with a gradually increasing target-to-noise ratio. After presentation without noise, the target-to-noise ratio decreases again, until the target can no longer be recognized or detected.

1.1. Pulse repetitions

An interesting result that came out of the test results is that the last detection threshold of repeated target sounds was on average lower than target sounds that were not repeated. An example of repeated target sounds that were used is like a telephone ringing. For this kind of repetitive sounds the last detection threshold was in some cases even 7dB lower than the first detection threshold, while the last detection threshold for sounds without repetition were on average 2dB lower than the first detection threshold. This means that the benefit of repetition for the last detection threshold is roughly 5dB. Offering repeated target sounds shifts the last detection threshold. The reason for this could be that the probability that at least one repetition is masked by the noise is smaller for sounds that come in repetition compared than for sounds with no or less repetitions. So for example, if you offer ten repeating target sounds combined with noise or offer three repeating target sounds combined with noise, then the probability is higher for ten repetitions that at least one pulse will not be masked by the noise. This is a statistical process that depends on the way noise is represented in the auditory system. Surprisingly no one has ever researched this phenomenon.

When applied to broadband noise, the auditory model used in Andringa's group leads to near Gaussian distribution of noise levels with a frequency dependent standard deviation of 2dB to 3dB. This means that a benefit of 5dB equals about two standard deviations of the noise's energy fluctuations.

Taking a normal distribution with a mean equal to the last detection threshold of a single pulse would mean that about 5 percent of the repetitions will be detectable at 2 standard deviations below the single pulse threshold. If more repetitions created a larger benefit, it could mean that even more repetitions will be detected while maintaining the same loudness. If this is correct then it means that the detection threshold is a statistical process, which indicates that the threshold detection value is a function of the number of repetitions and the standard deviation of noise in a normal distribution. We hypothesize that this is a Gaussian distribution. Hereby we aim to find the mean and standard deviation of this distribution with an experiment that resembles the experiment used by Andringa and Pals.

1.2. Pulse to tone

Another experiment investigates the difference between pulse-like and tone-like sounds. Pulses have a short duration and a wide frequency range, while tones have a long duration and a small frequency range. We therefore have the hypothesis that at least two different domains exist, at least a pulse-domain and a tone-domain. We aim to find the transition point that distinguishes these two domains. It is also possible that there is a gradual transition between the two extremes.

2. Experiment 1: pulse repetitions

2.1. Method

2.1.1 Participants

In this experiment 16 participants participated. All participants reported to have no hearing problems.

2.1.2 Equipment

The experiment uses a graphical user-interface and is designed in Matlab using a special psychophysics-toolbox called Psychtoolbox version 3 [3]. This toolbox gives Matlab additional functionality for creating psychophysical experiments. Experiments have been conducted in a quiet room. Unfortunately because of abnormal capacity usage of the experimental chamber this quiet room was not always used, instead sometimes another quiet room was used with another windows-running desktop. The participants were given Sennheiser 250HD headphones which have a closed air cup that block ambient sounds. All stimuli were presented at a level far above the ambient sound level.

2.1.3 Stimuli

Andringa and Pals used for their experiment everyday sounds coming from a subset of Gygi et al. (2007) and masked these with pink noise. Because we are interested in sounds that are repeated we choose to use computer generated pulses in Matlab. These pulses are sinusoids multiplied by a cosine. The sinusoids are so short that they do not represent a full period.

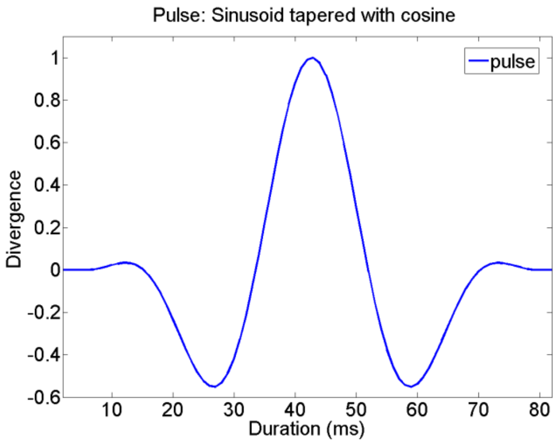

Figure 2 – Pulse generated in Matlab

We used a center frequency of 600Hz for the pulse-like target sound. One advantage of using computer generated pulses is that the pulses are reproducible. This means that we can duplicate the same pulse for multiple participants and versions of the experiment. For analyzing the data this can also be helpful. Also we have total control over the setting of the pulses.

The stimuli consisted of pink noise combined with N pulses and each stimulus had a duration of 3 seconds. The stimuli contain 0, 1, 2, 3, 6 or 10 pulses. The number 3, 6 and 10 can show irregular or regular inter-pulse intervals. We used pink noise because it is common in nature, and it distributes its energy evenly at the basilar membrane.

We cut 10 pieces out of a premade sample audio file consisting of pink. Each piece had a duration of 3 seconds The pieces were combined with target sounds in a subsequent order. To generate pink noise you have to create random numbers which results in white noise and then apply a filter to it. Pink noise is different from white noise in a way that the power density of pink noise decreases by 3 dB per octave while white noise has power over all frequencies. Pink noises density is proportional to 1/frequency (1/f) . For this reason, pink noise is often called "1/f noise".

2.1.4 Experimental design

The experiment consists of a training phase and a test phase. In the test phase there were 30 versions of each stimulus. Each version consisted of a random allotment of the number of pulses in the pink noise. Because of the 9 conditions (0, 1, 2, 6, 10 irregular pulse-intervals or 3, 6, 10 regular pulse-intervals) and 30 versions of each stimulus this makes a total of 270 stimuli. The condition with 0 pulses checks if participants were hallucinating pulses. If participants reported they detected a pulse while a stimulus with the 0-condition was presented, then they received a response that there was no pulse. But if they answered they didn't hear any pulse, then they would be informed there was no pulse indeed.

The order of presentation was random but fixed for every experiment. Our aim is to measure the 50%-point for every condition in which a minimum of 1 pulse is detected in the noise. So if a participant reported that a pulse was detected, then the next time a stimulus of that condition was presented the energy of the pulses were decreased by 1dB. If a participant reported not to have detected a pulse, then the next time a stimulus with that condition was presented the energy of the pulses were increased by 1dB. The loudness of the noise was never altered. This will result in an oscillation around the 50%-point, as visualized in figure 3.

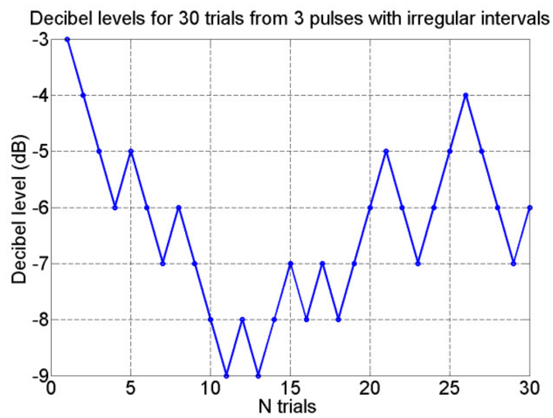

Figure 3 – Example of the progress of the experiment

The starting decibel levels per condition were predetermined by a pilot, the pilot's starting decibel levels were all set to 0dB. The pilot data gave us a raw indication on what decibel level the 50%-point per condition might be and to calculate the starting decibel levels we added 3dB to the 50%-point of the pilot. This way there was a higher probability of receiving data around the 50%-points.

2.1.5 Procedure

First the participants had to enter their name, date of birth and tell if they suffered from hearing loss. After that there was an introducing text message to explain how the experiment would progress. After reading this the training phase started. The participants were now presented with 10 stimuli, after each stimulus they had to report if they detected a pulse in the noise. If they answered yes then they were asked how many they had detected. After reporting how many pulses the participant had detected or answered no to the previous question, the participant received feedback if the given answer was wrong or right. After these 10 stimuli participants had to qualify 4 random stimuli correct. This training phase helps participants to get used to the stimuli and the experimental design. After the training phase came the test phase that consisted of 270 stimuli. This phase also contained the question if the participant detected a pulse. Now again, if a pulse was detected the participant was asked how many were detected. Feedback was also given with the condition with 0 pulses. After all 270 stimuli the program terminated automatically.

2.1.6 Measurements

In the test phase the decibel levels per condition were recorded. Also the number of pulses a participant had detected and the reaction time for every stimulus between the question if they detected a pulse and the answer were recorded.

2.1.7 Analysis

For every participant we determined the 50%-points by making histograms of the data. An example of a histogram of the condition of 3 irregular pulses of a participant can be seen in figure 4.

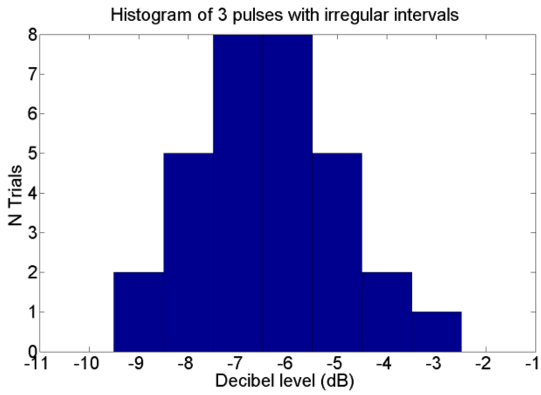

Figure 4 – Example of a histogram of 3 pulses with irregular intervals of 1 participant

Figure 5 shows the CDF (cumulative distribution function) of the histogram for 3 pulses with irregular intervals in figure 4.

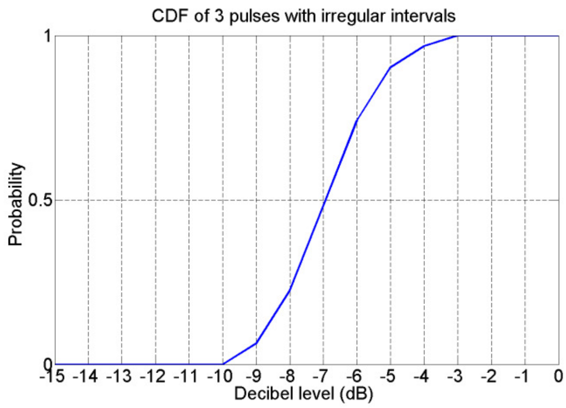

Figure 5 – Example of the CDF of figure 4 of 1 participant

The hypothesis is that the data will show a Gaussian distribution. For this to investigate we need to calculate the probability per given pulse and per detected pulse. The following formula is a binominal distribution [5] which calculates the probability of detecting a minimum of k pulses when n pulses are presented given a probability p. Probability p is the probability for the condition of k = 1 and n = 1, which is set to 0.5:

$$\sum_{k=\dots}^{n} \binom{n}{k}(p)^k(1-p)^{n-k}$$

Formula 1 – Probability calculation

We use this formula to calculate the probabilities that n pulses are presented and k pulses detected. Using this formula gives the probability distribution in table 1.

n k	1	2	3	6	10
1	0.5	0.75	0.875	0.98438	0.99902
2	-	0.25	0.5	0.89063	0.98926
3	-	-	0.125	0.65625	0.94531
6	-	-	-	0.015625	0.37695
10	-	-	-	-	0.00097656

Table 1 – Probability distribution according to formula 1 given p = 0.5

The variable n stands for N pulses present in the noise and k represents N pulses detected in the noise.

2.2. Results

The means per condition were calculated by taking the 50%-point of the CDF of figure 5. This point is where the probability on the y-axis is 0.5. Figure 6 shows the means per condition of all participants per condition (thin colored lines) and the mean over all participants per condition (thick black line) both for pulses with irregular intervals. The following data manipulation is analogous for pulses with regular intervals. Here the condition of 0 pulses is excluded, because it doesn´t provide any additional value.

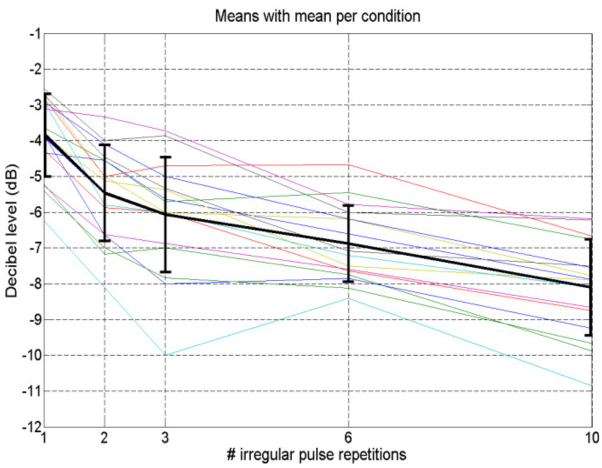

Figure 6 – Means of all participants per condition and mean over all participants per condition before correction

What is remarkable is that the individual performances can differ greatly at some conditions. An extreme example is shown at the condition with 3 pulses which shows a difference of almost 6dB between the lowest and the highest thin colored line. One possible reason for this is that every person has different detection thresholds. Fortunately the performances per participant show a same kind of direction. So to compensate this we subtracted the performances per participant with its own mean over all conditions and added the mean of the whole group of participants. This way the mean over all participants per condition is the same, but the differences (standard deviations) over all participants becomes smaller. The result can be seen in figure 7.

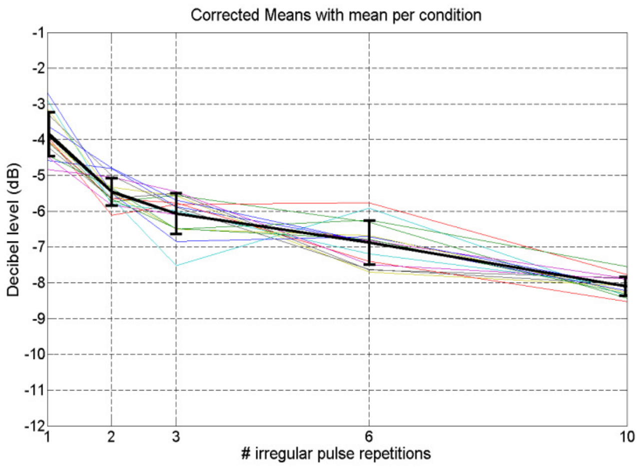

Figure 7 - Means of all participants per condition and mean over all participants per condition after correction

Figure 8 shows deviation of the performances per participant from the mean per condition on the top before correction and on the bottom after correction. For each plot the big blue line represents the mean of the condition and the small green lines represent the means per participant.

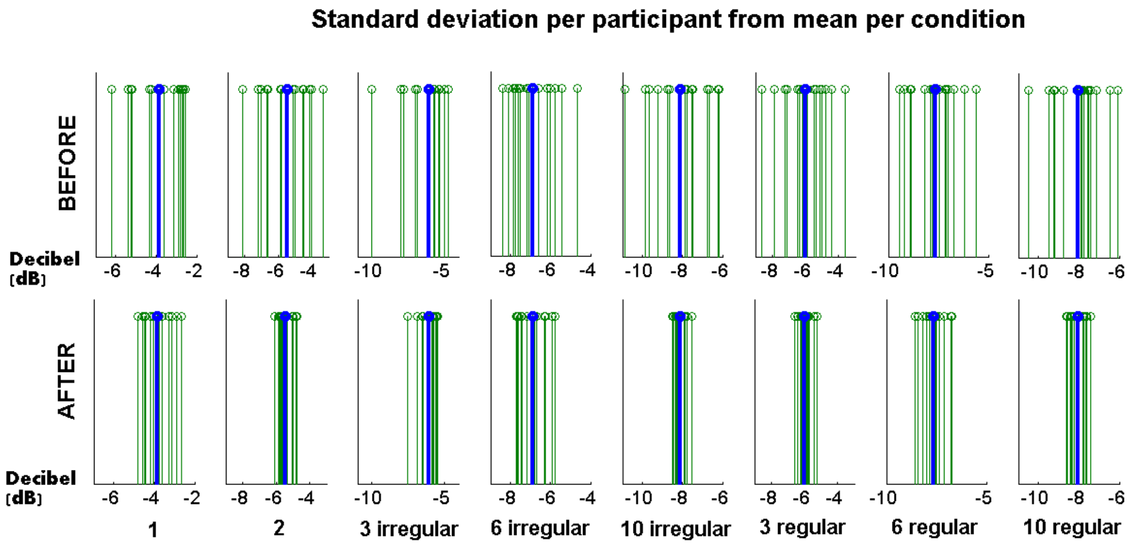

Figure 8 – Deviation of performances per participant from the group's mean and the deviation of all participants, both before correction

Figure 9 shows the detection thresholds of the mean over all participants for pulses with irregular and regular intervals.

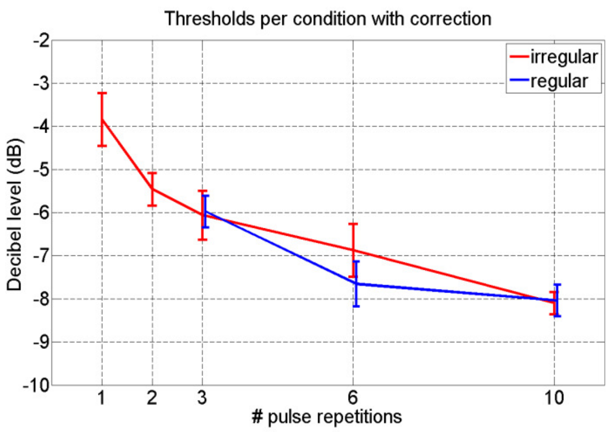

Figure 9 – Thresholds of mean over all participants for pulses with irregular and regular intervals

The thresholds decrease as the number of pulses increases. The regular thresholds compared to the irregular thresholds are almost identical for the conditions of 3 and 10 pulses. For 3 pulses the regular condition lies 0.0896 dB above the irregular condition and the difference in standard deviation is -0.20513. For 10 pulses the regular condition lies 0.0583 dB above the irregular condition and the difference in standard deviation is 0.10683. The threshold for the regular pulses for the condition with 6 pulses lies even 0.7788 dB lower than for 6 pulses with irregular intervals and the difference in standard deviation is -0.08438. To investigate if there are significant differences between pulses with irregular and regular intervals we took for the conditions 3, 6 and 10 two-sided paired t-tests [4] with α = 0.01. The difference between pulses with irregular and regular intervals for 6 pulses is very significant ($t(15) = 3.8015$, $p = 0{,}0017$). The difference between pulses with irregular and regular intervals for 3 pulses are not significant ($t(15) = -0.5369$, $< p = 0.5992$) as are not for 10 pulses ($t(15) = -0.4296$, $p = 0.6736$).

Table 2 shows the same as table 1, except that the probabilities are replaced by threshold values for pulses with irregular intervals rounded at 2 decimals. Table 3 shows the same but for pulses with regular intervals.

n k	1	2	3	6	10
1	-3.85	-5.46	-6.06	-6.88	-8.10
2	-	-4.40	-5.20	-6.66	-7.37
3	-	-	-4.34	-5.62	-7.10
6	-	-	-	-5.01	-6.76
10	-	-	-	-	-5.40

Table 2 – Detection thresholds for irregular pulses given p = 0.5

n k	1	2	3	6	10
1	-3.85	-5.46	-5.97	-7.65	-8.04
2	-	-4.39	-5.05	-7.20	-8.12
3	-	-	-4.43	-6.73	-7.42
6	-	-	-	-5.74	-6.35
10	-	-	-	-	-6.36

Table 3 – Detection thresholds for regular pulses given p = 0.5

The threshold values for k = 1 are determined using the 50%-points from section 2.1.7. All other threshold values have been calculated by first recording at which decibel levels participants guessed the right number of pulses, thus by checking the answers given from the experiment and comparing them with the predetermined list of pulses that are presented. For every combination of n and k there has been made histograms which behave like normal distributions. For every histogram a CDF was made and from there the threshold value was found by looking at the 0.5-probability point. This data analysis is equal to that of the 50%-points on section 2.1.7.

According to table 2 and 3 the size of the variable n determines how low the detection thresholds are, thus the larger the n the lower the thresholds. Even though, in theory if according to probability theories the probability is higher for a given condition, in practice the detection thresholds can be lower for a condition with lower probability. For example the detection threshold for k = 10 & n = 10 for irregular pulses is -5.40 dB with a very small probability of 0.00097656 to occur. The condition k = 3 & n = 3 has a higher probability of 0.125 but has a higher detection threshold of -4.34 dB. In theory a condition with a lower probability should have a higher detection threshold because the probability is lower for a minimum of 1 pulse to be detected. Data shows that this does not work in practice.

Because the theory only seems to account for k = 1 it is best to only correlate between the detection thresholds of k = 1 and the corresponding probabilities. The values for k = 1 are surrounded by red lines at table 2 and table 3. Figure 10 and figure 11 show the detection thresholds of respectively table 2 and table 3 set out against the probabilities of k = 1 according to table 1.

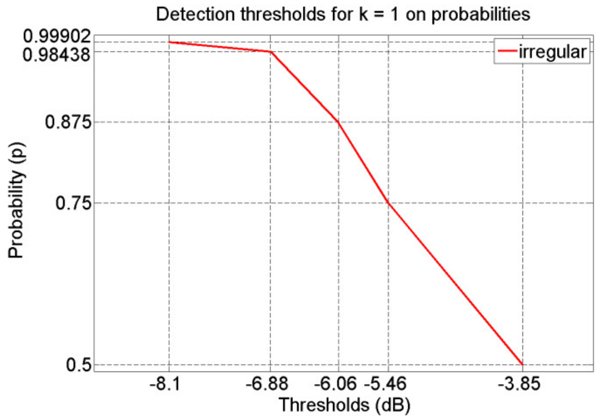

Figure 10 – Detection thresholds for pulses with irregular intervals of k = 1 with corresponding probabilities

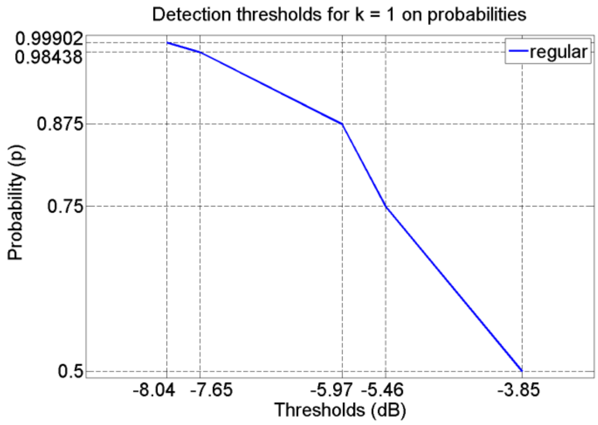

Figure 11 - Detection thresholds for pulses with regular intervals of k = 1 with corresponding probabilities

The values of table 1 are the probabilities of detecting a minimum of k pulses when n pulses are presented. In order to make a Gaussian fit of the data we have to use the probabilities of not detecting a minimum of k pulses when n pulses are presented. This means that every new probability is equal to 1 minus the old probability according to table 1. Figure 12 shows the detection thresholds of irregular pulses for k = 1 set out to the new probabilities with a CDF fit with mean = -3.917 and standard deviation = 1.897. Figure 13 shows the same with regular pulses with a CDF fit with mean = -3.899 and standard deviation = 1.971. The lower graph of both figure shows the deviation of the fit from the data.

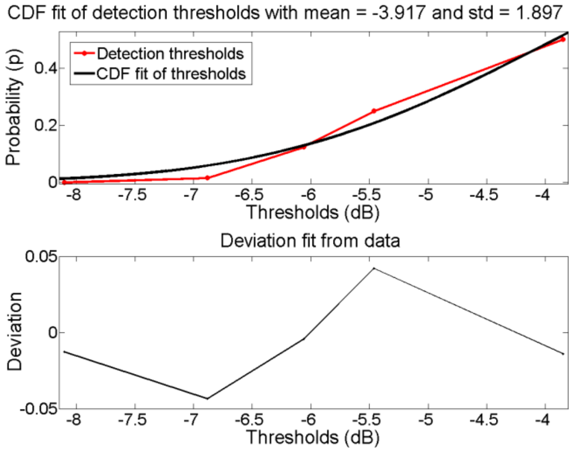

Figure 12 – CDF fit of irregular detection thresholds with mean = -3.917 and standard deviation = 1.897

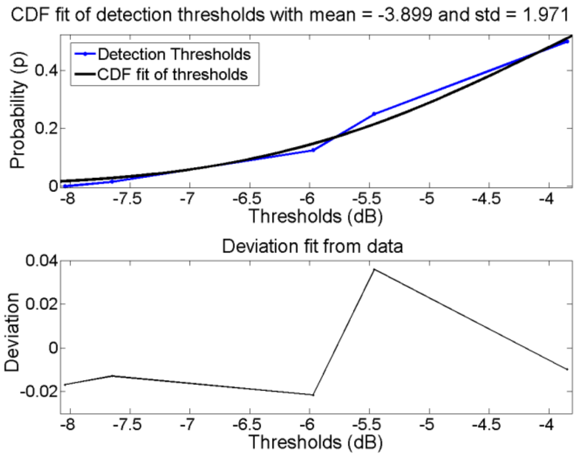

Figure 13 – CDF fit of regular detection thresholds with mean = -3.899 and standard deviation = 1.971

The mean of the irregular fit is 0.018 lower than the regular fit and the standard deviation of the irregular fit is 0.074 lower than the regular fit.

2.3. Discussion

- The difference between the irregular fit and the regular fit is small, therefore we can calculate the average of the two fits. The average mean is -3.908 and the average standard deviation is 1.934.

- Figure 10 and figure 11 only show the upper part of the distribution from 0.5 to 1 probability (left part from the mean). This is because of the inconsistent data that accounts for the lower part of the distribution from 0 to 0.5 probability (right part from the mean). A possible reason for the lack of consistent data is that the calculation of these thresholds is an indirect calculation and is not so reliable. In some stimuli the inter pulse time interval were small which makes it difficult to count the individual pulses in combination with paying attention to detect a pulse. Participants had to choose between 0, 1, 2, 3, 6 and 10 pulses for answering how many pulses they detected. If participants don't exactly know how much pulses they detected they make a guess between the answers that are prohibited. This is why this threshold calculation can be unreliable and inaccurate. For this reason we cannot make a full fit of a Gaussian distribution (or any distribution) on the data.

- There is a significant difference between irregular and regular repetitions with 6 pulses, but the effect is small. There is no significant difference with 3 and 10 pulses. Even though, this might be a small indication that there is a difference between pulses that have irregular or regular intervals. Because the detection threshold for regular intervals is lower, it is possible that pulses with regular time intervals contain cues for the detection of pulses. One cue might be that by hearing 3 or more pulses with a regular time interval lets participants prime for the next position in time where the upcoming pulses might be located. This cue is not provided by pulses with irregular time intervals.

- For giving a clearer view of the significant difference between pulses with irregular and regular intervals given 6 pulse repetitions we wish to have more data points between 3 and 10. Then also we would have more information about the shape of the curve what gives us more accuracy interpreting the test results. The main reason we did not do this in the first place is that the experiment would have been too long. It requires more conditions and with more conditions comes more trials. The current experiment takes about 30-45 minutes to finish, adding more conditions will only increase its duration. This will eventually have a negative effect on the performances as there is an increase in probability that participants start losing their focus. A solution may be to decrease the number of versions per condition, but this is not for the benefit of the number of data points required to get an accurate and clear view of the detection thresholds.

- The effect of priming can sometimes also be seen when participants show oscillations at lower decibels as they progress. Sometimes participants even show two oscillation points while examining their histograms as like having two 50%-points (detection thresholds) in one condition. This phenomenon is rare in the data. Participants can be primed by the same condition attending on number of pulses, but it is also possible that participants are primed by all conditions as every condition contains the same pulse. This means that the effect of priming can be seen in every condition.

- Evaluation of this experiment brought that participants often reported that the last ± 30 trials contained different noise. They asked if we changed the noise in those trials, which is not the case. Some participants experienced louder noise, other participants said they heard creaky sounds that were different from the target sounds and the noise. These effects can come from long exposal of noise and target sounds which results in hallucinations. This is an interesting effect of adaptation to the stimuli.

3. Experiment 2: pulse to tone

3.1. Method

3.1.1 Participants

In this experiment 19 participants participated. From this group 17 participants reported that they did not suffer from hearing loss, while 2 participants reported to suffer from hearing loss. Analysis showed that the performances of these 2 participants did not differ from the average performances of the other participants. Therefor all 19 participants were used for analysis.

3.1.2 Equipment

This section is equal to section 2.1.2 of experiment 1.

3.1.3 Stimuli

We are interested in targets that lie on the continuum domain between pulses to tones. Figure 14 shows cochleograms of the 9 sounds that were created, from pulse-like to tone-like sounds in 9 steps with a center frequency of 600Hz. The steps are characterized by time intervals and for each step from pulse to tone the duration is increased. The upper left cochleogram shows a pulse-like sound and the bottom right cochleogram shows a tone-like sound. Sound duration increases from left to right. While the duration increases the frequency range decreases. As you can see the pulse-like sounds are short and have a wide frequency range, while the more tone-like sounds are long and have a small frequency range. Colors indicate the degree of energy, it ranges from blue (low degree of energy) to red (high degree of energy). Each cochleogram has a maximum energy around 600Hz, because sounds were produced with a 600Hz carrier wave of which the envelope was manipulated.

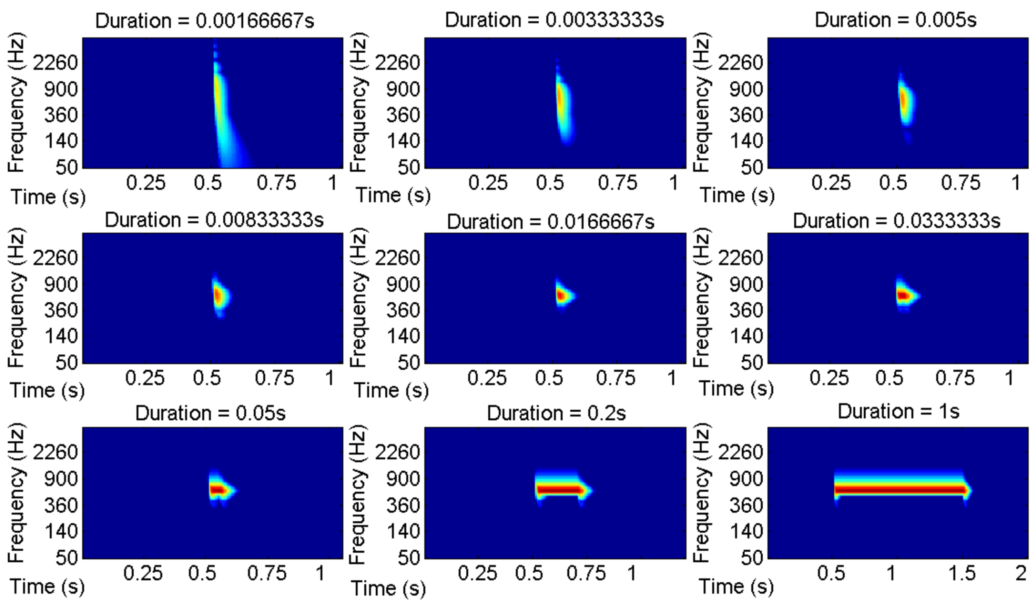

Figure 14 – Cochleograms of 9 target signals

Condition	1	2	3	4	5	6	7	8	9
Seconds	0.0017	0.0033	0.005	0.0083	0.017	0.033	0.05	0.2	1

Table 4 – Table of 9 conditions with their corresponding durations

Table 4 gives the conditions with the corresponding durations.

This gives us 9 conditions plus a condition with 0 pulses, which is a total of 10 conditions. The stimuli were created from a combination of a sound from a condition combined with pink noise. Each stimulus has a duration of 3 seconds.

3.1.4 Experimental design

This section is equal to section 2.1.4 of experiment 1, except that 10 conditions were used instead of 9 conditions. The 10 conditions and 30 versions lead to a total of 300 stimuli. Figure 15 shows an example of the progress of the experiment for 1 participant.

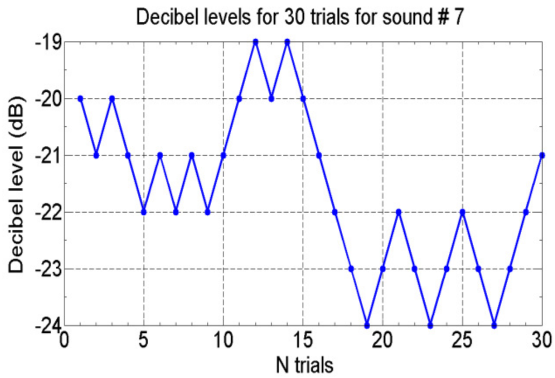

Figure 15 - Example of the progress of the experiment

3.1.5 Procedure

This section is equal to section 2.1.5 of experiment 1, except that the test phase did not consist of 270 stimuli but of 300 stimuli.

3.1.6 Measurements

In the test phase the decibel levels per condition were recorded. Also the reaction time for every stimulus between the question if they detected a sound other than noise and when they gave their answer was recorded.

3.1.7 Analysis

For every participant we determined the 50%-points by making histograms of the data. An example of a histogram of the condition of a target sound with a duration of 0.05 seconds of a participant can be seen in figure 16.

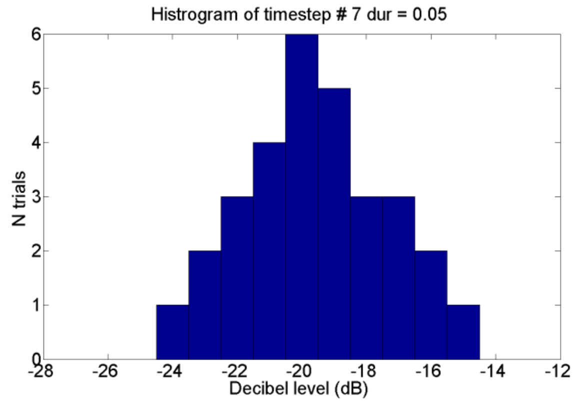

Figure 16 - Example of a histogram of a sound with time step # 7 and duration of 0.05 seconds

Figure 17 shows the CDF (cumulative distribution function) of the histogram of figure 16.

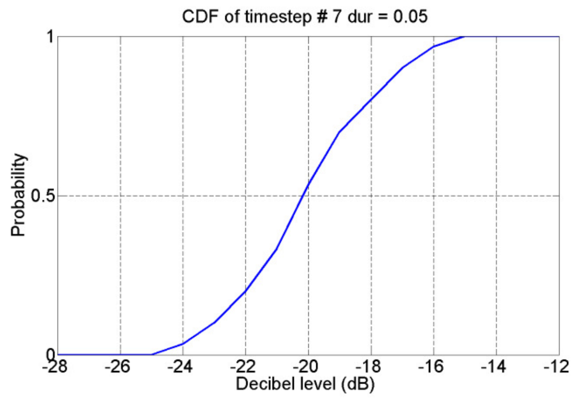

Figure 17 - Example of the CDF of figure 16

3.2. Results

The means per condition were calculated by determining the 50%-point of the CDF. This point can be seen in figure 17 by the corresponding probability of 0.5 as seen on the y-axis to the value on the x-axis. Figure 18 shows the means per condition of all participants per condition (thin colored lines) and the mean over all participants per condition (thick black line). Here the condition with 0 pulses is not presented, because it doesn´t contain any additional value. The x-axis has been altered at a logarithmic scale, because time steps between conditions are also taken at a similar scale.

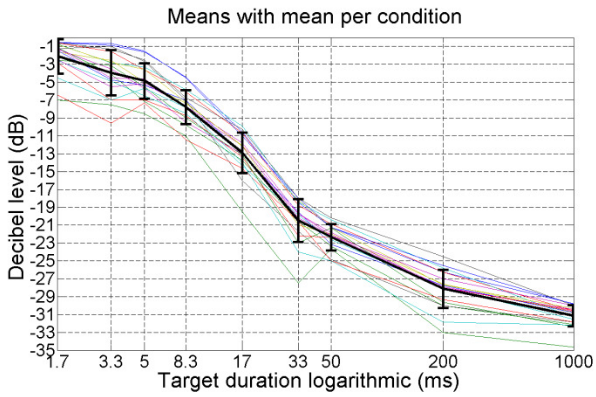

Figure 18 - Means of all participants per condition and mean over all participants per condition before correction

What is remarkable is that the performances per participant can differ greatly at some conditions. One possible reason for this is that every person has different detection thresholds. Fortunately the performances per participant show a same kind of direction. So to compensate for this we subtracted the performances per participant with its own mean over all conditions and added the mean of the whole group of participants. This way the mean over all participants per condition remains the same, but the differences between participants becomes smaller. The result can be seen in figure 19. Figure 20 shows deviation of the performances per participant from the mean per condition on the top before correction and on the bottom after correction. For each plot the big blue line represents the mean of the condition and the small purple lines represent the means per participant.

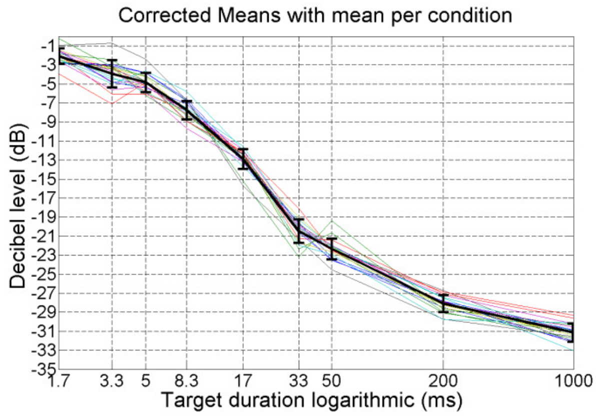

Figure 19 - Means of all participants per condition and mean over all participants per condition before correction

Figure 21 shows the detection thresholds per condition over all participants. The curve has a bending point at a duration of 0.033 seconds. The slope of the curve ranging from point 1 to point 6 steepens, but from point 6 to point 9 the slope becomes more flat. This might be an indication that there is a transition point between the pulse-domain and tone-domain at point 6.

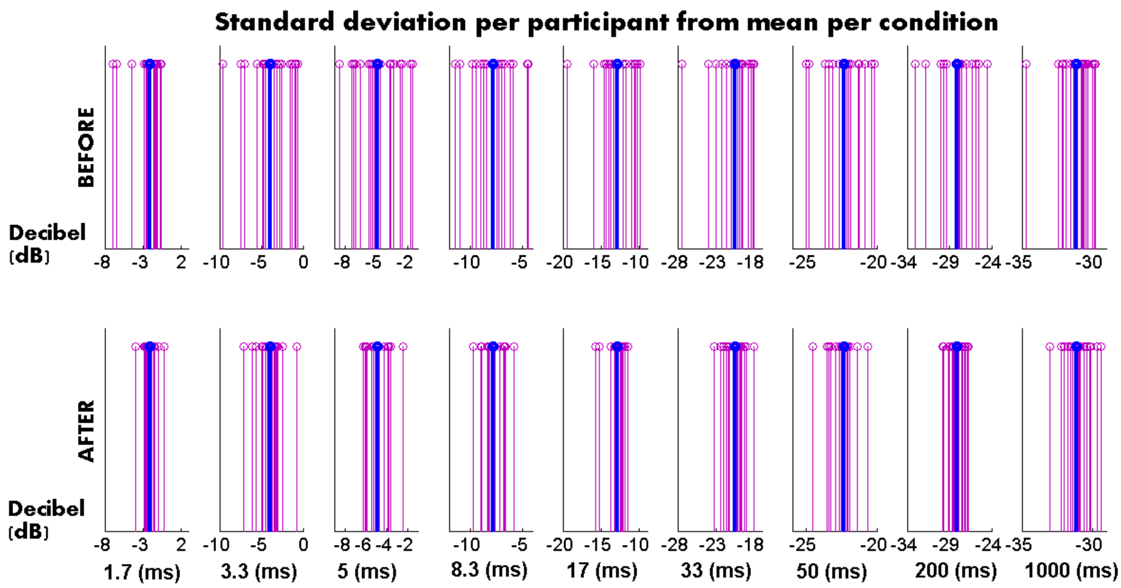

Figure 20 – Deviation of performances per participant from the group's mean and the deviation of all participants, both before correction

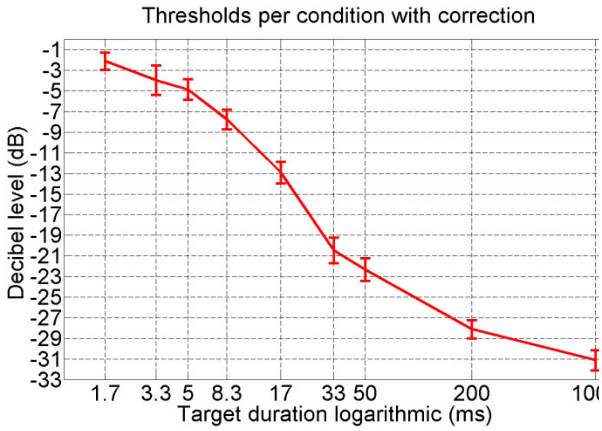

Figure 21 - Thresholds of mean over all participants

3.3. Discussion

- A sound with a wide frequency range and a short duration has a lower probability of being detected in the noise than a sound with a small frequency range and a long duration. A sound that has a longer length clearly has a bigger area to differ from the randomness of the noise. And therefore any deviation from the noise will have a higher probability of being detected by the participants. This means that a sound that is tone-like can have a lower detection threshold because of its characteristics of a longer duration than a pulse-like sound has. A pulse-like sound therefore has a higher detection threshold.

- The inflexion point at point 6 only is an indication of the existence of a transition point between the pulse-domain and the tone-domain. It has a duration of 0.033 seconds which seems a bit short for a tone-like sound but it seems that it contains cues for people to sometimes classify it as a tone-like sound. The target sounds has a center frequency of 600Hz which means that 1 period has a duration of 0.0017 seconds, a target sound with a duration of 0.033 seconds therefore has almost 20 periods. The growing steepness between point 1 and point 6 indicates that the target sound gains length and changes more from a pulse-like sound to a tone-like sound. The inflexion point at point 6 and the decreasing steepness from point 6 to point 9 indicates that a larger increase in target length has less effect for the target sound being classified as a tone-like sound.

- This experiment has only been conducted using sounds with a center frequency of 600Hz. Perhaps there might be more information if we took multiple experiments with each a different kind of center frequency.

- We choose to use data of all 19 participants for analysis, including the 2 participants that reported to suffer from hearing loss. This is because performances of these 2 participants did not differ from the other 17 participants that did not reported to suffer from hearing loss. Sometimes the data of one of the participants that reported not to suffer from hearing loss was even more different from the performance of the average of all participants than a participant that reported to suffer from hearing loss.

4. References

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