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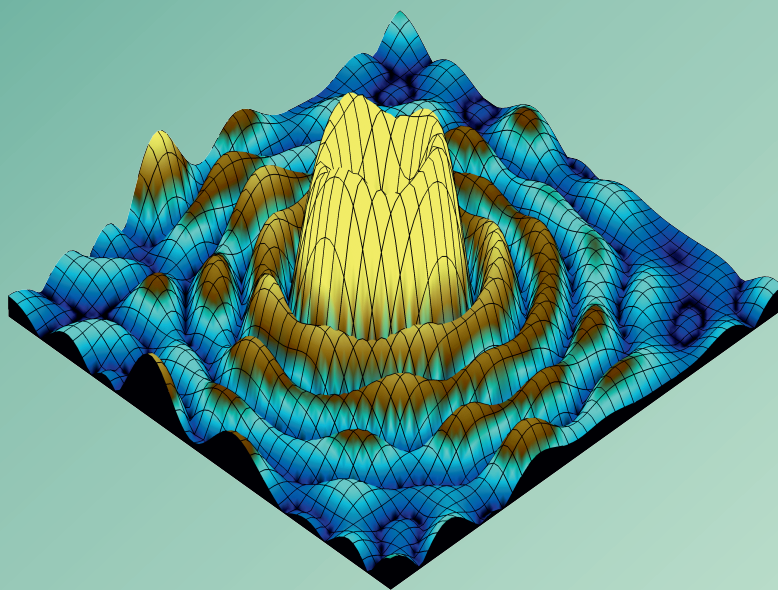
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Przedmowa

Akustyka jest nauką żywą i nieustannie rozwijającą się, a dynamiczny postęp techniczny stworzył dla akustyki olbrzymie możliwości badawcze w skali mikro i makro, dzięki czemu możemy uzyskać wiele cennych informacji o strukturze materii, materiałach, konstrukcjach, a także o organizmach żywych, w tym organizmie człowieka. Należy podkreślić interdyscyplinarny charakter akustyki, której rozwój wymaga nie tylko konieczności ujęcia zjawisk od strony fenomenologicznej, lecz także poszukiwania ich interpretacji matematycznej i fizycznej oraz rozpatrywania zjawisk akustycznych z punktu widzenia innych dyscyplin naukowych. Jest to możliwe przez powiązanie akustyki z osiągnięciami dyscyplin naukowych z zakresu nauk ścisłych, technicznych, biologicznych i medycznych, a także nauk humanistycznych.

Niniejsza monografia zawiera 55 recenzowanych rozdziałów wielu autorów, przedstawiających swoje najnowsze badania z zakresu akustyki biomedycznej, akustyki budowlanej, akustyki fizycznej, akustyki mowy, akustyki muzycznej, akustyki środowiska, akustyki wnętrz, badania materiałów, bioakustyki, elektroakustyki, hydroakustyki, przetwarzania sygnałów, psychoakustyki, ultradźwięków i walki z hałasem. Prace te zostały zaprezentowane 13–16 września 2016 roku na LXIII Otwartym Seminarium z Akustyki w Białowieży organizowanym przez Oddział Warszawski Polskiego Towarzystwa Akustycznego.

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Preface

Acoustics is the active and constantly developing science and dynamic technical progress has created tremendous opportunities for acoustics research at micro and macro scale. Thanks to it we can obtain many valuable information about structure of matter, materials, constructions and also about living beings including human body. The interdisciplinary nature of acoustics must not be forgotten as its development requires not only the approach to the phenomena from the phenomenological point of view but also the search of its mathematical and physical interpretation and the consideration of acoustical phenomena from the perspective of other science disciplines. It is possible by the interrelation of acoustics and the achievements of scientific disciplines in the field of science, technical, biological and medical sciences as well as humanities.

This monograph includes 55 reviewed chapters of many authors presenting the resent research in the field of biomedical acoustics, building acoustics, physical acoustics, speech acoustics, musical acoustics, environmental acoustics, room acoustics, non-destructive testing and evaluation, bioacoustics, electroacoustics, hydroacoustics, signal processing, psychoacoustics, ultrasound and noise control. The above mentioned works were presented at 63rd Open Seminar on Acoustics in Białowieża (13–16.09.2016) organized by the Warsaw Division of the Polish Acoustical Society.

Editor: Mirosław Meissner

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GRID - A FAST THRESHOLD TRACKING PROCDURE

A new procedure, called "grid", is evaluated that allows rapid acquisition of threshold curves for psychophysics and, in particular, psychoacoustic, experiments. In this method, the parameter-response space is sampled in two dimensions within a single run. This allows the procedure to focus more experimental time investigating the vicinity of the sought-after threshold curve, compared to the current state-of-the-art methods. Therefore, time-efficiency is significantly increased and may be suitable for clinical diagnosis. While the described procedure can be used to track threshold curves in various psychoacoustic experiments, its use for measuring temporal masking curves (TMCs), based on forward masking is presented in the present study. Thresholds obtained in TMC experiments using a standard adaptive method and the new method, in a detection task, are comparable (i.e., very highly correlated).

1. INTRODUCTION

Forward masking experiments are of particular interest in current audiological research. They are believed to enable diagnosis of the state of the inner ear by estimating the input-output function of the basilar membrane (BM I/O). Individual hearing-aid fitting (e.g., compression ratio and compression threshold settings) might benefit from such extended diagnosis.

Nelson et al., [1] suggested a forward-masking based paradigm for behavioural measurements of BM I/O functions. They derived the functions from temporal masking curves (TMCs). Within that paradigm, the masked signal is fixed at a low level (10 dB sensation level; SL) and masker thresholds were found as a function of the masker-signal interval. Two conditions are distinguished in the task. In an "on-frequency" condition, the masker and the signal are pure tones of the same frequency. In an "off-frequency" condition, the masker's frequency is set at 40-60% of the signal's frequency. In the first condition the masker may be compressively processed at

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the BM-site where the signal is processed, depending on the state of the cochlea. However, in the second condition, the masker is always linearly processed at the signal-site. The BM I/O is derived by pairing off-frequency and on-frequency thresholds according to the masker-signal interval. Thus, the off-frequency TMC is used as a linear reference for the on-frequency curve.

While TMC-based procedures have potential diagnostic applications, they are not used clinically, due to low time-efficiency. Apart from the extensive training required, the main reason is as follows. Individual masker-thresholds depend on the hearing loss (hearing threshold, BM I/O characteristics) and on the response criterion of an individual listener. Thus it is difficult to *a priori* choose a small set of masker-probe gaps that will lead to a large dynamic range of threshold estimates, in all listeners [2-3]). Hence, one needs to test a large set of masker-probe gaps, spanning a large masker-probe gap-range, which leads to long testing times. Moreover, while testing large masker-probe gaps may be needed for some listeners, it may lead to testing at uncomfortable levels for other listeners.

Here, a novel, time-efficient, threshold tracking method was tested, called the "grid method" [2]. This method adaptively adjusts both the masker level and the masker-signal gap within each experimental run. This enables the placement of a higher proportion of trials in the vicinity of the sought threshold curve, when compared to more traditional threshold-tracking methods. Moreover, the grid method does not require defining a small set of masker-signal gap values as it tests the combinations of masker levels and masker-signal gaps in a selective way.

While the method was already used in multiple-interval discrimination design [4], it has not been assessed in single-interval, detection tasks, where the time-efficiency is better [5] because of the fewer intervals presented in a single trial. The reference method, used here, was the single interval up-down (SIUD) method [5] - one of the most time-efficient threshold tracking methods that is currently available. TMC thresholds were estimated with both methods, in groups of normal-hearing (NH) and hearing-impaired (HI) listeners.

2. METHOD

2.1. LISTENERS

Single ears were tested from 6 NH and 5 HI participants. The NH group consisted of 5 males and 1 female with mean age of 27. Each of these participants had thresholds below 20 dB HL at all audiometric frequencies (250-8000 Hz). The HI group consisted of 3 females and 2 males. Their mean age was 53 and all of them exhibited a mild-to-moderate sensorineural hearing loss (25-70 dB HL). The selection was

based on the audiogram and the air-to-bone conduction gap, which did not exceed 10 dB at the tested frequencies. The procedure was approved by the National Research Ethics Committee of Denmark.

2.2. STIMULI AND TEST PROCEDURE

The stimuli were the same in both experiments. The maskers were 200 ms pure tones gated with 4 ms raised cosine ramps. The signals were Hanning windowed, 16 ms pure tones with an 8 ms steady-state portion. Throughout all forward masking experiments, the signal level was fixed at 12 dB SL. This level is used instead of 10 dB SL level from Nelson 2001, to make the task perceptually easier for the listeners. All stimuli were generated on a PC running Matlab and a 24 bit RME soundcard. The presentation was monaural via Sennheiser HDA200 headphones in a double-walled booth.

First, the absolute thresholds for the signals were estimated. Subsequently, the listeners were trained in the forward masking task (for at least two hours) before data collection. The experiments using the grid method were conducted first and 4 repetitions were run in each condition (on-frequency condition at 1, 2 and 4 kHz and off-frequency condition at 4 kHz) for thresholds estimation. Next, the experiments using the SIUD procedure were run with 3 repetitions per condition. The number of repetitions is higher in the grid method since the gap-sets tested in two individual runs may not be identical, due to variations in listener's response. Executing four runs increased the probability of having 3 individual estimates for each tested gap. To facilitate comparison, the masker-signal gaps considered with the SIUD were the same as the gaps for which the threshold was estimated from the grid method.

2.3. THE GRID PROCEDURE

The basic assumption of the grid method is that the threshold curve is monotonic. The assumption holds in TMC experiments, because for any combination of masker-probe gap and masker level, the probe-detection task can be simplified by increasing at least one of the two parameters. Thus, a TMC is a non-decreasing function of masker-probe gap. A sketch of a TMC is shown in figure 1.

A monotonic threshold curve divides the two-parameter space into two disjoint regions. In figure 1, the two regions are labelled "audible" and "inaudible". The labels describe salience of the target probe, relative to the salience at threshold. Thus, the probability of a listener detecting and reporting the probe in the "audible" region is higher than at threshold, and lower in the "inaudible" region. Consequently, if for a given combination of masker-probe interval and masker-level, a listener reports the

presence of a probe (a positive response, in figure 1), it can be assumed that the parameter combination resides below and to the right of the sought-after threshold curve. Thus, in order to decrease the probability of a positive response ("cross" the threshold curve), the masker-probe gap has to be decreased or the masker level increased. The grid method aims at maximizing the amount of experimental time spent in the vicinity of the threshold curve, by maximizing the number of times the threshold curve is crossed.

A grid-method experimental run starts by defining the maximum and minimum allowable masker levels and masker-signal gaps. Next, a set of masker-signal gaps and a set of masker levels are chosen to span corresponding ranges. Here, the set of allowable gaps was 1, 2, 4, 8, 12, 16, 24, 32, 48, 64, 80, 96, 128, 160 and 192 ms. The minimum masker level was set to 3 dB less than the fixed signal level, while the maximum level was set to 85 dB SPL for NH listeners and up to 110 dB SPL for HI listeners. The masker level step size was fixed at 3 dB and, together with the masker level limits, a list of allowable levels was defined, which always included the lower limit.

The initial gap was set to 160 ms and the initial masker level was set 6 dB above the probe level, where the probe was expected to be easy for most listeners. In case of the off-frequency TMCs, the initial level was set to 12 dB above the probe level, to reflect the fact that off-frequency thresholds are usually higher than the corresponding on-frequency thresholds.

Next, a pair of initial search directions were set. The first direction was "leftwards", (i.e., decreasing masker-probe gap) and it was followed while listener could detect the masker-probe gap (positive response in figure 1), since decreasing the gap increases the difficulty of the detection task. The second direction was set to "downwards" (i.e., decreasing masker-level, decreasing task's difficulty) and it was followed while listener could not detect the masker-probe gap (negative response in figure 1).

During an experimental run, one of the lower boundaries is reached as a result of following the "leftwards-downwards" pair of directions. In order to continue the run, the pair of directions was changed to "rightwards-upwards". Importantly, if the task-difficulty was being decreased (by decreasing the masker level) immediately before the change and no reversal occurred at the boundary, the difficulty was still being decreased immediately after the change, by increasing the masker-signal gap. By analogy, if the difficulty was being increased before the change (decreasing the masker-probe gap), it is still increased after the change, by increasing the masker level.

Following the new pair of directions, the masker-probe gaps and masker-levels were successively increased, until one of the upper boundaries was reached, where the second and last change of the direction pair was executed and the run finished. The first change of the direction-pair was used to mark-off the initial phase of the test-run and the response probabilities at the tested gap-level pairs were estimated only between the first and the second change of directions. Simple linear interpolation of the response probabilities was used for threshold estimation purposes.

The task of the listener was to report the presence of the signal, i.e., a yes/no task. Catch trials [6] were used in 50% of cases to form an additional perceptual anchor. The absence of the signal was the only difference between a catch trial and a corresponding test trial. If the listener gave a positive response in three consecutive catch trials, the procedure was restarted and the listener was given further instruction. Otherwise, the catch trials did not influence the test.

The first stimulus in each run was a test trial. The second was a catch trial. Subsequently, pairs consisting of a test trial and a catch trial were presented and the order of the trials was randomized.

The tracking rule was analog to the 1-up-1-down rule and it can be considered as 2-up-2-down. In the 1-up-1-down tracking method, a "yes-no" reversal occurs when a series of one or more consecutive, positive responses of a listener is interrupted by a negative response (see figure 1, where the 1-up 1-down rule is sketched). A "no-yes" reversal occurs when a series of one or more consecutive, negative responses is interrupted by a positive response. Here, a "yes-no" reversal occurred when two consecutive listener's responses were negative and a "no-yes" reversal occurred if two consecutive listener's responses were positive. The choice was made in order to decrease the influence of random responses near threshold. This rule is expected to track the 50% threshold.
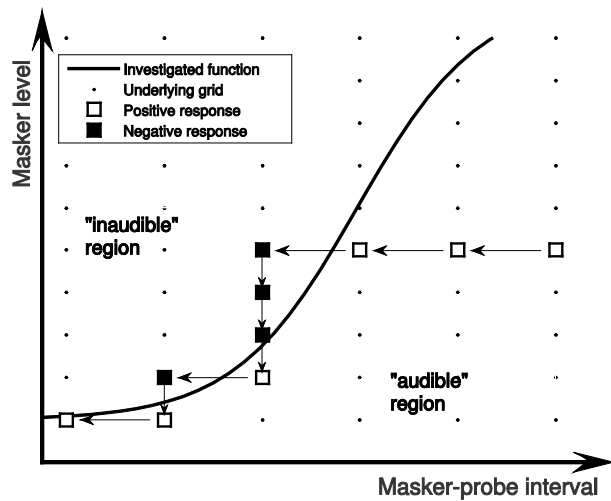
Figure. 1. A hypothetical TMC (solid line) is shown, together with the „audible" and „inaudible" regions. The dots show the masker-probe interval – masker level pairs, where listener's response can be tested during an experimental run, i.e., the underlying grid. Importantly, only a subset of the pairs is tested, depending on listener's responses. The open and filled squares represent positive and negative listener's responses, respectively, which correspond to detection of the probe. The arrows indicate the testing order.

The masker level was varied adaptively (1-up-1-down) based on the participant's responses (yes/no). Within a single run, the masker-signal interval was fixed. An initial step size of 10 dB was used. After 2 reversals, the step size was decreased to 6 dB and after the next 2 reversals, it was further reduced to 2 dB. Up to 12 responses were collected using the smallest step size and the run was stopped earlier when the within run standard deviation of the collected responses fell below 3 dB. A catch trial was presented always on the second trial and more catch trials were presented at random (with 20% probability) during a single run. Unlike in Lecluyse and Meddis 2009, no cueing interval was used here. During pilot tests some listeners found the cue distracting, rather than helpful.

3. RESULTS

The thresholds obtained with the two methods were paired with respect to the masker-signal gaps. If at least one data point was collected for a particular gap using each of the methods, these data points were taken into the comparison. Figure. 2 shows the results obtained with the two methods.

The R^2 coefficient calculated for all paired data-points, measured for all listeners, was 0.91 (p<0.0001). The mean difference between the corresponding thresholds was 2.6 dB and the standard deviation was 5.7 dB.

Additionally, correlations were calculated for each individual's data. The values of R^2 ranged from 0.7 to 0.97, with a mean of 0.88. All correlations were significant, with the p values never exceeding 0.003 and less than 0.0001, in most cases.
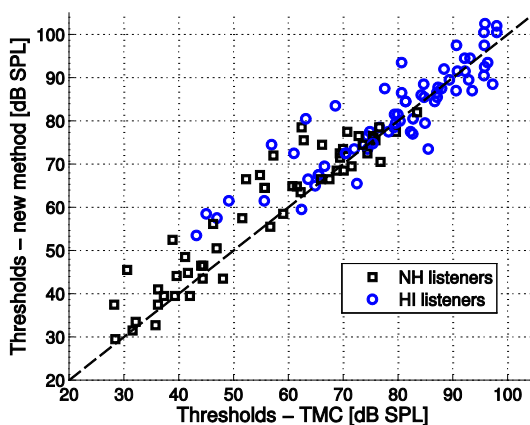

Figure. 2. The scatterplot of threshold estimates from the SIUD-TMC (abscissa) and the present method (ordinate). The R2 coefficient was 0.91 and the correlation was significant at p<0.0001. The mean error estimate was 2.6 dB and the standard deviation was 5.7 dB.

As a comparison, an R^2 coefficient was calculated for data collected in the different runs using the SIUD procedure. For each masker-signal gap tested within each TM curve, two out of three measured thresholds were taken, at random. This formed two sets of thresholds and the between-set correlation coefficient indicates the within-run consistency of the SIUD TMC procedure. The corresponding mean value of R^2 was 0.9, with the standard deviation of 0.01, which was very similar to the correlation between methods. The comparison of the correlation coefficients suggests that the accuracy of the grid method was similar to that of the SIUD method.

The time efficiency of the two methods was compared based on the number of signal presentations needed to estimate a single threshold. The mean number of signal presentations (excluding catch trials) used in the grid method was 8.1 with a standard deviation of 2.8, whereas for the SIUD method the mean number of signal presentations was 16.1 with the standard deviation of 2.8.

4. DISCUSSION

4.1. TIME-EFFICIENCY

The main motivation of this work was to compare the grid method to the SIUD method in a detection task. Since the grid method evaluates several thresholds during a single experimental run and SIUD evaluates one threshold per run, the investigation of the time-efficiency of the grid method was based on the number of signal presentations needed to estimate a single threshold. Here, it was estimated that the grid method requires about two times fewer signal presentations to estimate a threshold than the SIUD method. Moreover, the results show that a single run of the grid method, where a threshold curve is estimated, takes about 3 minutes, which roughly corresponds to the time needed to evaluate 2-3 thresholds with the SIUD method

However, these comparisons should be considered as a rough estimate as many factors can influence the measurement time, such as step-size, stopping criteria, and the details of the tracking rules. For instance, the SIUD method might use two step sizes (10 and 2 dB) instead of the three (10, 6 and 2 dB) used here, while the grid method might use the 1-up-1-down tracking method which is expected to double the number of thresholds obtained within a single experimental run

The evaluation here, however, confirmed that the grid method offers a superior control over the tested dynamic range. Of the 148 curves obtained with the grid method, the lowest maximum masker level sampled during an experimental run was 78 dB SPL and all other cases were 80 dB SPL or higher. This is one of the most important advantages of the grid method over standard adaptive methods like SIUD, which do not guarantee testing of a pre-defined dynamic range.

4.2. ACCURACY

The evaluation presented here confirmed that the accuracy of the grid method is comparable to that of the standard methods. The value of the R^2 coefficient of correlation of the thresholds obtained with the grid method and the SUD method was high, at 0.91. Moreover, the minimum value of the R^2 coefficient of correlation, measured for 11 individual listeners, was 0.7 and the mean value of the corresponding distribution was 0.88. These results suggest good accuracy and reliability of the grid method. However, the thresholds obtained with the grid method were, on average, 2.6 dB higher than corresponding thresholds obtained with the SIUD method. Several sources of this estimate bias were considered: a training effect, subjective difference in the difficulty of the task between the investigated methods, the grid method's step size and a directional bias.

It is unlikely that this bias is due to a training effect for two reasons. First, the listeners were well trained before conducting the experiments. Second, the order of experiments was such that the runs of the grid method were conducted before the corresponding runs of the SIUD method. Thus, if the training effect was the source of the investigated bias, the thresholds obtained from the SIUD method should have been higher than those obtained from the grid method. This was not the case.

The other two possible sources of the estimate bias, the step size and the directional bias, are both related to the details of the experimental procedure used to investigate the grid method and they are not mutually exclusive. The step size of the grid method (measured along the ordinate) was 3 dB and the set of tested masker levels was fixed. This limited the maximum accuracy of the method and further investigation is needed to characterize the relationship between the method's step size and accuracy. Second, within a single run of the grid method, the threshold curve was sampled by increasing of the masker-level or the masker-signal gap. This could lead to a direction-related bias since the thresholds were obtained only from the parts of a run where the gap was fixed and the masker level was increased. Thus, the direction of masker-level change could have been a source of the investigated bias.

Some of the listeners reported that they perceived the experiments performed with the grid method as "easier", compared to those performed with the SIUD method. This is surprising, given that the stimuli presented in both experiments were generated with the same procedure. However, if the subjective perception was correct, it would partially explain the positive bias.

5. SUMMARY AND CONCLUSION

While several psychoacoustic measures may be clinically useful, standard threshold tracking methods used in psychoacoustical experiments are usually not feasible in

a clinical setting. The GRID method was developed to substantially increase the time-efficiency compared to traditional methods. This time-efficiency is achieved by changing the way the parameter-response space is sampled to allow more flexible setting of parameter values during a single experimental run.

In the evaluation results presented here, thresholds obtained with the grid method were highly correlated with those from one of the standard methods (overall $R^2 = 0.91$, individual R^2 values all greater than 0.7). Importantly, time efficiency and effectiveness were shown to be markedly better than those of the standard methods. Despite some limitations (e.g., the assumption that the underlying threshold curve is monotonic) the method offers promising flexibility and accuracy.

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