THE PERCEPTION OF FLUCTUATING SOUNDS BY HEARING-IMPAIRED LISTENERS

J.A.P.M. de Laat

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THE PERCEPTION OF FLUCTUATING SOUNDS BY HEARING-IMPAIRED LISTENERS

J.A.P.M. de Laat

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

Many hearing-impaired subjects have difficulties in understanding speech in situations with interfering sounds (e.g. competing talkers, traffic noise, music). In previous dissertations from our laboratory, Festen (1983) and Dreschler (1983) have tried to explain these difficulties on the basis of deteriorated primary auditory functions like frequency resolution and temporal resolution. Their findings showed that these auditory functions can be responsible for only part of the speech-perception problems by the hearing impaired.

A possible explanation for this result may be that the primary auditory functions studied were too remote from the parameters involved in speech understanding to be fully succesful. The rapidly fluctuating speech signal seems to ask for a comparison with more complex stimuli to get a better insight into the underlying factors of deteriorated speech perception. This holds the more in view of the finding that a single competing voice (Duquesnoy, 1983), or a rapidly varying noise (Festen and Plomp, 1986b), interferes much stronger with speech intelligibility of hearing-impaired subjects than steady-state noise. Apparently, it is worthwhile to supplement the previous studies with new experiments in which sound stimuli with widely divergent sorts of spectro-temporal fluctuations are involved.

The present study presents the results of a series of experiments selected to meet this demand. In each of them the perception of particular complex sounds by hearing-impaired subjects is investigated. In order to reduce the number of disturbing factors as much as possible, the same group of 20 test subjects was used in most experiments. This has the important advantage that interrelations of the data from the various tests can be studied by means of correlation techniques. In the next sections these experiments are shortly introduced.

Periodically disturbed sound signals (Chapter 2)

Several investigators have given attention to the phenomenon that a pure tone interrupted, for example, five times per second, can be heard as a continuous signal when the interruptions are filled with noise. Surprisingly, this continuity effect, studied by Dannenbring and Bregman

(1978) and Bregman and Pinker (1978), holds also for tones modulated in amplitude or in frequency (Plomp, 1980). Some conditions for the continuity effect to exist are studied for normal-hearing subjects (e.g. sound-pressure level of tone and noise (Thurlow, 1957), tone-noise period (Houtgast, 1974), effect of modulation (Van Noorden, 1975), synchrony (Bregman, 1978)), whereas nothing is known for hearing-impaired subjects.

One of the possible parameters in an experiment with modulated tone pulses interrupted by noise pulses is the lowest repetition rate of the pulses, for which the tone can be perceived as continuous. Part of the difficulties of speech perception in noisy conditions, especially for the elderly, may be connected to the capacity to 'extract' sounds fluctuating in time and/or in frequency against dynamic interfering sounds.

Sweeping masker (Chapter 3)

Smoorenburg and Coninx (1980) investigated the masking of short probe sounds by tone bursts with a sweeping frequency. The masked threshold appeared to be higher than the threshold found for stationary maskers. The increase in masked threshold cannot be understood from models based on detection of energy increments in critical bands. An increase in loudness of the sweeping masker, however, could be understood on the basis of an effect of bandwidth on loudness and the assumption of an integration mechanism for loudness (Nabelek, 1979).

We investigated whether this behaviour, found for normal-hearing listeners, can also be observed for hearing-impaired listeners. Many hearing-impaired listeners have problems in understanding speech, being a fluctuating sound, especially against a background of noise. This suggests that the effect of a sweeping masker may be greater for them than for normals.

Synchronous sound signals fluctuating in time (Chapter 4)

Sensorineurally hearing-impaired subjects need an up to 10 dB higher signal-to-noise ratio to understand speech compared to normal-hearing subjects (Plomp, 1986). This holds for stationary noise. For hearing-impaired subjects the increase in signal-to-noise ratio has to be even greater if the ambient noise fluctuates in time and/or varies in frequency. Apparently, these subjects have large problems in perceiving a fluctuating stimulus disturbed by other fluctuating sounds.

We studied this phenomenon with synchronous tone sequences, as in polyphonic music fragments, by varying the frequency distance of the voices. The recognition of a melody of four succeeding tones, synchronously presented with two other tone series, was investigated as a function of the frequency distance between the three tone series. As far as is known no research on this phenomenon has been done. The results give insight into the disturbed perception of music by hearing-impaired listeners.

Segmented speech (Chapter 5)

It is well known that in speech signals the consonants are affected most by hearing impairment (e.g. Revoile, 1982). The reason might be that co-articulation (the transition between consonant and vowel), considered to be important for the recognition of consonants for normal-hearing subjects, is too subtle for hearing-impaired subjects (e.g. Godfrey and Millay, 1978).

By presenting speech segments (with or without a background of noise) of the type consonant-vowel and vowel-consonant, we investigated in which way consonant identification by hearing-impaired listeners is affected by elimination of vowel parts (Klaassen-Don, 1983).

Speech reception in fluctuating noise conditions (Chapter 6)

In quiet the speech-reception threshold (SRT) is closely related to the pure-tone threshold (Dreschler and Plomp, 1980; Festen and Plomp, 1981). Many investigations have been published on the relation between the SRT and different auditory functions (e.g. Moore, 1984; Rosen and Fourcin, 1986). In those studies the SRT data were obtained for stationary noise.

We investigated the SRT in noise, interrupted in time or filtered in frequency, comparable to daily-life situations, and more suitable to describe the handicap of hearing-impaired people.

Relations between auditory functions (Chapter 7)

Finally, the results of the speech-reception threshold experiments in different noise conditions are compared with differences in pure-tone threshold, auditory bandwidth, temporal resolution, continuity threshold, masking effect of short noise probes by frequency sweeps, and melody recognition threshold. Their relations are discussed.

The results of the measurements with fluctuating sound stimuli are pointed out particularly in the explanation of the decreased speech intelligibillity in noise, which is an important factor in the handicap of hearing-impaired people.

CHAPTER 2

THE PERCEPTION OF CONTINUITY IN INTERRUPTED TONE STIMULI

(abstract appeared in De Laat and Plomp, 1984a)

Summary

The continuity threshold of normal-hearing and hearing-impaired listeners was measured for bursts of pure tones alternated with noise bursts (equal duration of tone and noise bursts). In the first experiment the tone bursts included three types: constant frequency, modulated in frequency, increasing frequency. For the normal-hearing subjects the sound-pressure level at the continuity threshold is lower for large tone-noise periods than for short periods. For the hearing-impaired subjects it was difficult to obtain consistent results. Therefore, we carried out another experiment, in which the tone-noise period varied from 100 ms to 800 ms and the tone level varied over a range of 40 dB around most comfortable level. A special measuring technique (tone stimuli superimposed on or interrupted by a single noise burst) made it possible to obtain highly consistent and reliable results. Again for the normal-hearing as well as for the hearing-impaired subjects the continuity threshold drops to lower tone-burst levels for larger tone-noise periods. The range of the transition between the perception of continuity and discontinuity is larger for the hearing-impaired than for the normal-hearing listeners due to more variability and to a greater effect of hysteresis. We also found some relations with other auditory functions measured.

2.1 INTRODUCTION

In the past, several investigators (Thurlow, 1957; Thurlow and Elfner, 1959; Elfner and Homick, 1966; Bregman and Campbell, 1971; Dannenbring, 1974; Houtgast, 1974; Thurlow and Erchul, 1978; Plomp, 1981) showed that under certain conditions the human ear perceives tone bursts alternated with noise bursts as a continuous tone stimulus. This phenomenon is called the continuity effect. Thurlow (1957) studied the perception of pure tones with low sound-pressure level (SPL) alternated with tones with higher SPL. Under certain conditions the tones with low SPL seemed to sound continuously; he interpreted this phenomenon as an auditory figure-ground effect.

We may define the transition of perceiving the tone continuously or pulsating as the continuity threshold (denoted as the pulsation threshold by Houtgast, 1974). In most experiments only the continuity effect for pure tones was studied. For normal-hearing listeners the continuity threshold is rather independent of the tone-noise period over the range 2-8 tone bursts per sec.

One of the aims of the present investigation was to see if there is any relation between the perception of speech in practice and the perception of fluctuating (or pulsating) stimuli in an experimental condition. Normal-hearing listeners have a better understanding of speech in noisy situations than hearing-impaired listeners. When the speech is alternated with noise bursts the understanding is better than when the speech is alternated with silent intervals (Miller and Licklider, 1950; Powers and Wilcox, 1977).

In the first experiment we used three types of tone bursts with (1) the frequency constant, (2) the frequency modulated, and (3) the frequency gradually increasing. We applied an adjustment procedure to find the continuity threshold. Van Noorden (1975) studied the continuity effect with amplitude-modulated tone bursts. The tone bursts were alternated by noise bursts or by short "bursts" of silence. Continuity was perceived more clearly in the case of noise bursts than in the other case. Plomp (1981) reported the same results for frequency-modulated tone bursts. Both authors described experiments with normal-hearing subjects.

One of the reasons for using three different types of tone bursts is the fact that Bregman (1978) found that stream formation and segregation is sensitive to frequency distinction, rhythm and order. Dannenbring and Bregman (1978) stated that asynchronous components form, in general, horizontal streams more easily than synchronous components. From the experiments of Bregman and Pinker (1978) and also of McAdams and Bregman (1979) it follows that sequential and simultaneous effects, frequency separation and onset/offset synchrony are important determinants of perceptual fusion.

In the second experiment (to acquire more consistent and reliable results) we only used bursts of pure tones with constant frequency. In this case we applied a two-alternative forced choice procedure for 512 successive stimuli presented in one test sequence to each subject. The experiments described were carried out with both normal-hearing and hearing-impaired listeners.

2.2 EXPERIMENT 1

a. Procedure

For a fixed tone-noise period (equal duration of tone and noise bursts) the test was started at a level below the absolute threshold for the tone, so the listener only heard the white-noise bursts (at a sound-pressure level of 70 dB/Hz). The subject was requested to increase the level of the tone. Over a certain range he heard the tone stimulus continuously; further increasing of this level resulted for almost all subjects in hearing a pulsating tone. The subject had to turn the knob back again, to lower the level of the tone, until he heard the tone as a continuous tone and not as a pulsating one. From this moment the subject was free to turn the knob backward and forward in order to find the transition point between hearing a continuous and a pulsating tone stimulus. This point is the continuity threshold. The subject had to do this adjustment three times so that the reproducibility of the settings could be checked. In this way the threshold was measured for tone-noise periods of 200, 400 and 600 ms.

Subsequently the procedure was repeated, but now with a fixed tone level and the tone-noise period to be adjusted, starting with the long tone-noise period (heard as a pulsating tone). The fixed levels were chosen according to the range of adjustments obtained in the first part of the experiment. These constant test levels differed 5 dB from each other.

The experiment was carried out with the following tone stimuli: (1) constant-frequency bursts of 1000 Hz, (2) 5-% frequency-modulated bursts around 1000 Hz, modulation frequency 15 Hz, (3) gradually increasing frequency with seven bursts, 1 octave around 1000 Hz (Fig. 1).

All tone bursts were alternated with white-noise bursts, with cut-off frequencies of 125 Hz and 8000 Hz, and a sound-pressure level of 70 dB(A), both for the normal-hearing and the hearing-impaired listeners.

b. Apparatus

The experiments were performed with a computer, controlling sine and white-noise generators, filters, attenuators, switches, timers and gates (Fig. 2). The rise and fall times of the tone bursts were 15 ms (cosine-squared onset and termination).

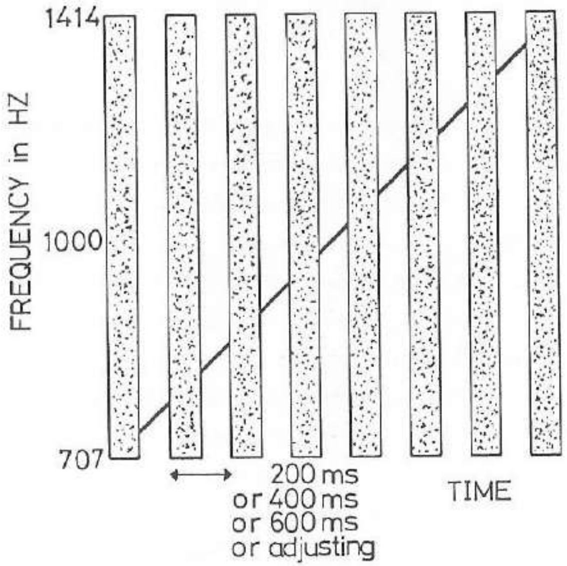


Fig. 1. Temporal and spectral structure of the frequency sweep. The dotted bars represent the noise bursts, the interrupted line represents a sweeping pure tone.

The subjects operated a knob to either adjust the level of the tone bursts with fixed tone-noise period or to adjust the tone-noise period of the bursts with fixed sound-pressure level. The tests were performed monaurally by earphone for the ear with the lower hearing loss averaged over 500, 1000 and 2000 Hz.

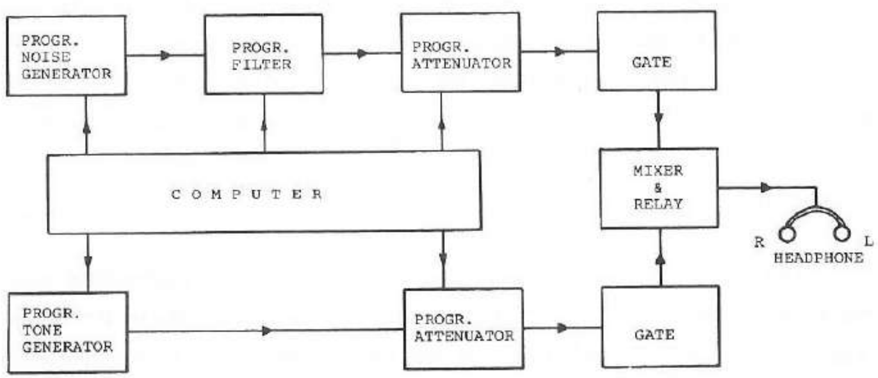


Fig. 2. Apparatus.

c. Subjects

The experiments were carried out with a group of 10 young normal-hearing subjects and a group of 10 pupils of a high school for the hearing impaired. All listeners were aged between 16 and 23. Only sensorineural hearing impairment was considered. In Fig. 3 the audiometric data of the hearing-impaired subjects are plotted with the mean values for the 10 normal-hearing subjects as a reference. The normal-hearing listeners had no previous experience in psychophysical experiments; they were trained in order to obtain reliable results. The hearing-impaired listeners had been subjects in earlier psychophysical tests. All subjects were paid for their participation.

d. Results for the normal-hearing listeners

The mean continuity thresholds for the normal-hearing subjects are shown in Fig. 4. In the panels 4a, b, and c both the results for fixed tone-noise periods and for fixed tone levels are presented. In each case the level of the stimulus is plotted as a function of the tone-noise period.

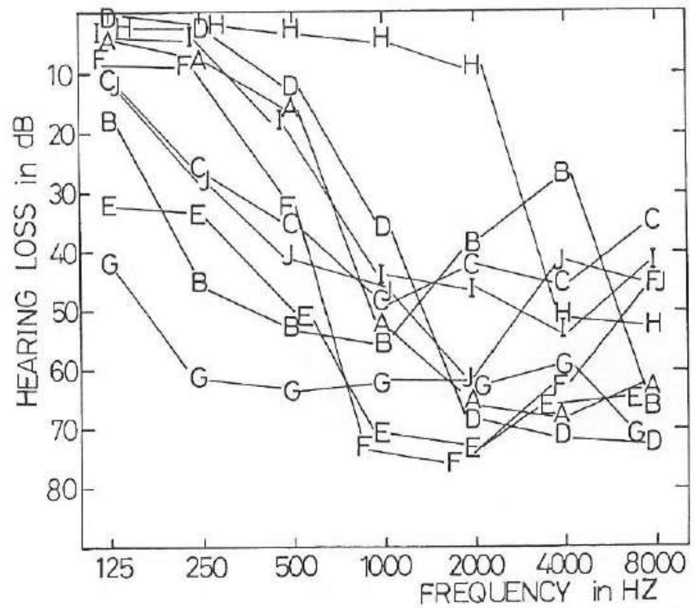


Fig. 3. Audiograms of 10 hearing-impaired subjects (individually represented by capitals) relative to the mean audiogram of 10 normal-hearing subjects.

Fig. 4a represents the continuity threshold for a pure tone of 1000 Hz. This threshold is not independent of the tone-noise period. For increasing tone-noise period the level of the tone must be reduced to perceive the tone continuously. Apparently, to integrate the tone bursts, the level of the tone bursts may reach higher values for shorter periods than for larger periods. Fig. 4b gives the continuity threshold for a frequency-modulated tone and Fig. 4c the threshold for a frequency sweep. For the three conditions the threshold level of stimuli measured with fixed tone-noise period is, on the average, higher than the threshold level of stimuli measured with fixed level, but these differences are not statistically significant (in Fig. 4b the standard deviations are larger than in Figs. 4a and c). The slopes of the threshold curves of the stimuli with fixed tone-noise period do not differ significantly from the slopes of the threshold curves of the stimuli with fixed level. We see that the level of the tone must be reduced for increasing tone-noise period in order to perceive the tone continuously. This experiment was also carried out for an amplitude-modulated tone; the results are comparable to the results for the frequency-modulated tone and are not reproduced here.

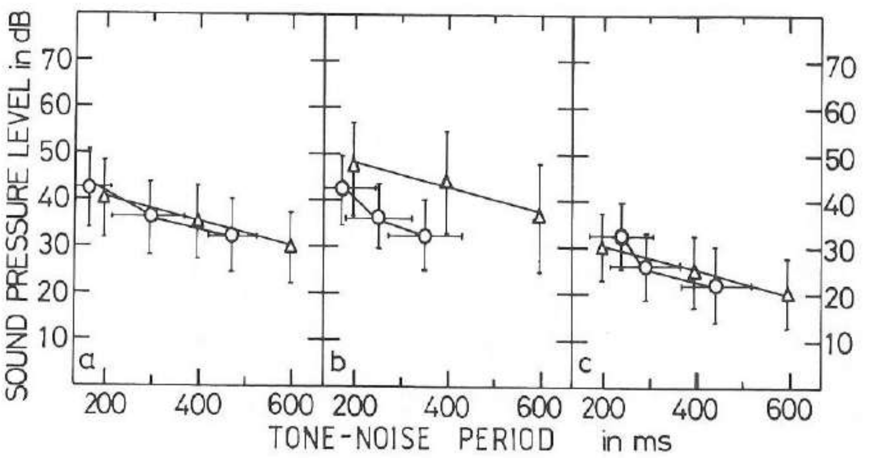


Fig. 4. Mean continuity threshold for a pure tone (panel a), for a frequency-modulated tone (panel b) and for a frequency sweep (panel c) for 10 normal-hearing subjects (triangles for fixed tone-noise periods, circles for fixed tone levels; fixed tone levels chosen according to the range of adjustments obtained for fixed tone-noise periods). The bars represent the standard deviation.

Comparing the three panels of Fig. 4, we see that the level to reach the continuity threshold is lower for the frequency sweeps than for the two other stimuli. This effect is significant ($P < 0.05$) for the results for fixed tone levels but not significant for the results for fixed tone-noise periods. It should be remarked that the interindividual differences in the continuity thresholds were rather large; however, the general tendency of a lower threshold level for larger tone-noise period is significant; the mean slope of the curves is -54 dB/sec with a standard deviation of 51 dB/sec.

e. Results for the hearing-impaired listeners

The continuity threshold for the hearing-impaired subjects differed so much from subject to subject that the results are plotted individually in Fig. 5. In the panels a, b and c, the results for fixed tone-noise periods are plotted for pure tones, frequency-modulated tone bursts and frequency sweeps, respectively. The results for the subjects indicated with E, F and G are withdrawn, because there was almost no difference (< 10 dB) between hearing threshold and continuity threshold for these listeners (which had to be expected referring their pure-tone thresholds). This was not the case for the other subjects.

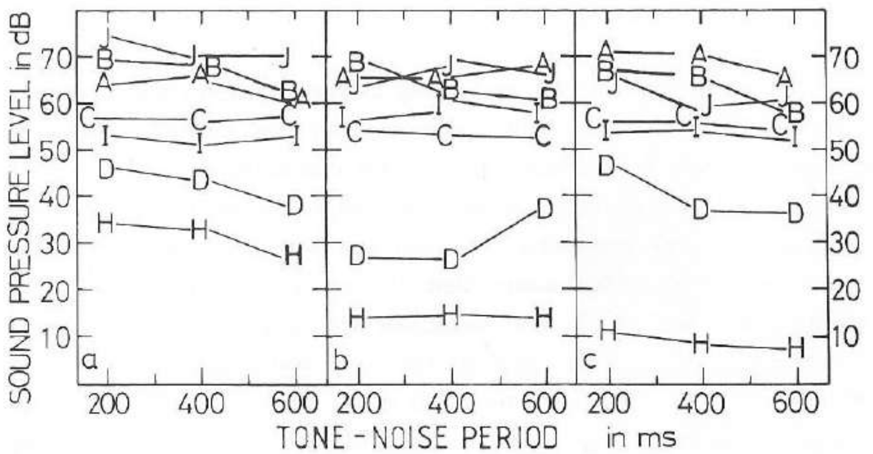


Fig. 5. Continuity threshold for a pure tone (panel a), for a frequency-modulated tone (panel b) and for a frequency sweep (panel c) for 7 hearing-impaired subjects (fixed tone-noise period data, subjects individually represented by capitals).

There was no significant difference between the mean values of the threshold levels of the stimuli with fixed level and the stimuli with fixed tone-noise period. There was also no significant difference between the continuity thresholds measured with a pure-tone, frequency-modulated tone or frequency sweep.

The reliability coefficient for the hearing-impaired listeners, estimated from the correlation coefficient (r) between test and retest applying the formula of Spearman and Brown (Nunnally, 1967) equal to $2xr/(1+r)$, is only 0.58. Most phenomena (such as slope of the curves, type of tone stimulus, and type of measurement), except the level of the continuity threshold itself, show no influence of the hearing threshold. The continuity-threshold values are, on the average, 20 to 30 dB above the mean continuity-threshold values of the normal-hearing listeners.

The difference between the results for the normal-hearing listeners and the hearing-impaired listeners is only significant ($P<0.05$) for the results for fixed tone-noise periods; the slope of the curves for the normal-hearing listeners is steeper than for the hearing-impaired listeners, whereas the threshold levels are lower for the normal-hearing listeners than for the hearing-impaired listeners. This means that hearing-impaired listeners perceive continuity in conditions that normals hear pulsation (for equal SPL).

f. Discussion and conclusions

The results for the normal-hearing listeners indicate that there are three different regions in the perception of the dynamic stimuli: a continuity region, a transition region and a discontinuity region.

For the normal-hearing subjects as well as for the hearing-impaired subjects, often the continuity threshold was almost independent of the tone-noise period, which means that it was difficult to measure the threshold at fixed levels, and sometimes the continuity threshold was almost independent of the level of the tone, which means that it was hardly possible to measure the threshold at fixed tone-noise periods. These phenomena are related to the effect of hysteresis. For a listener, hearing a continuous stimulus, the continuity region is larger before "reaching" the discontinuity region, than, hearing a pulsating stimulus, before "reaching" the continuity region.

For the normal-hearing listeners the sound-pressure level of the tone at the continuity threshold was lower for the frequency sweeps than for the two other stimuli, which difference was significant ($P < 0.05$). For the hearing-impaired listeners the tendency was the same but not significant. An explanation for this phenomenon might be the fact that the listeners expected the continuity of the interrupted tones (around one frequency) more than the continuity of the interrupted frequency sweep (due to more variation). This effect may be closely related to typical central processes: the figure-ground effect, the closure-principle, proximity and similarity of signals (grouping mechanisms).

2.3 EXPERIMENT 2

a. Procedure

The presented stimulus consisted either of two short tone bursts separated by a noise burst (Fig. 6a) or of a long tone burst with a noise burst superimposed (Fig. 6b). The subject was requested to decide whether he heard one single tone burst or two successive tone bursts; he should not take notice of the noise burst.

Due to the continuity effect, the response in the case of Fig. 6a as well as Fig. 6b is "one" as long as the level of the tone burst(s) is sufficiently low with respect to the level of the noise burst. In the case of Fig. 6a there will be a transition from one to two perceived tone bursts when the level of these bursts is increased more and more. We used the responses on the stimulus of Fig. 6b to "check" the reliability of the test.

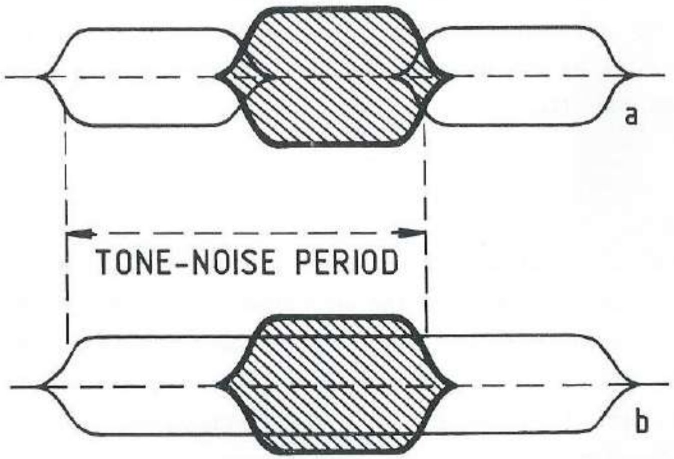


Fig. 6. Two stimuli: a) two pure-tone bursts separated by a noise burst; b) one pure-tone burst with a noise burst superimposed.

It turns out that for high levels of the noise burst there is no different percept of stimuli a and b, for low levels there is a clear difference and for levels in between there is no clear difference: the region of the continuity threshold.

If the number of stimuli of type 6a would be equal to the number of stimuli of type 6b, the responses would not be divided equally: both responses ("one" and "two") on stimuli of type a, only responses "one" on stimuli of type b. So we presented eight stimuli in each condition, of which six stimuli consisted of two tones (type a), and two stimuli consisted of one tone (type b).

The stimuli were presented in 64 different conditions: eight different levels of the 1000 Hz tone (steps of 10 dB around most comfortable level), and for each level eight different tone-noise periods (steps of 100 ms from 100 ms to 800 ms) with tone bursts and noise bursts of the same duration. The total number of stimuli was 512 (64 times 8). The stimuli were presented in random order. The test lasted about 20 minutes and was repeated the next day, in order to estimate the reliability of the experiment. The white-noise bursts were presented with cut-off frequencies of 125 Hz and 8000 Hz and a sound-pressure level of 70 dB(A).

b. Apparatus

The experiments were performed with a computer, controlling sine and white-noise generators, filters, attenuators, switches, timers and gates (Fig. 2). The rise and fall times of the tone and noise bursts were 15 ms (cosine-squared onset and termination). The tests were performed monaurally by earphone for the ear with the lower hearing loss averaged over 500, 1000 and 2000 Hz.

c. Subjects

Twenty hearing-impaired subjects with sensorineural loss participated in this experiment. The distribution of the audiograms of the subjects is plotted in Fig. 7. As can be seen there is a great spread in hearing level of the participating subjects. The subjects were between 13 and 17 years old and were pupils of a high school for the hearing-impaired.

Ten normal-hearing subjects of the same average age and at the same educational level as the hearing-impaired subjects also took part in the experiments, to serve as a reference.

All subjects were unexperienced in psychophysical tests, but were trained to get reliable results. They were paid for their services.

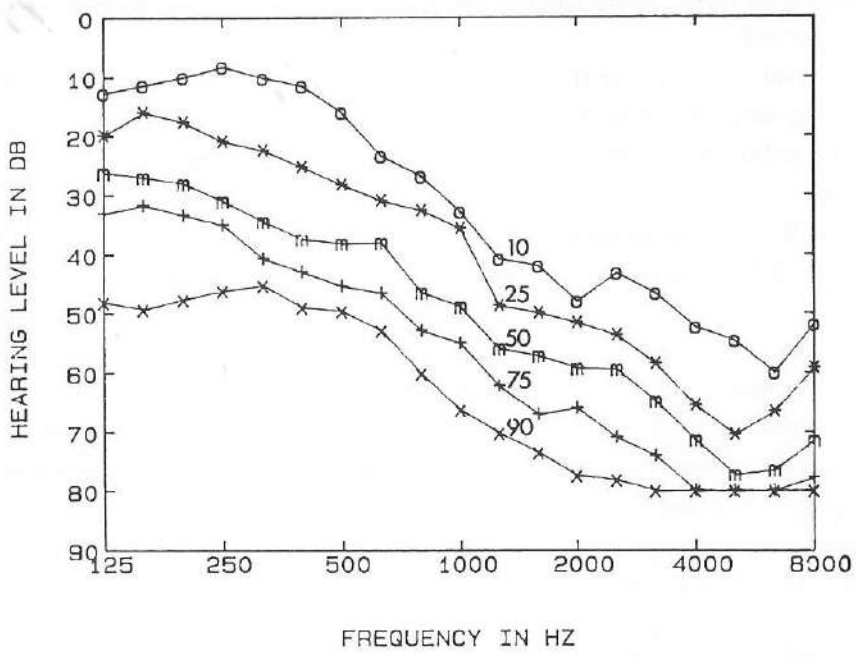


Fig. 7. Distribution of the audiograms of 20 hearing-impaired listeners with reference to the mean audiogram of 10 normal-hearing listeners. The numbers indicate the percentage of subjects whose hearing levels were better than the indicated values.

d. Results

As mentioned before, 64 different stimulus conditions (eight tone levels and for each level eight tone-noise periods) were presented to the listeners. Every condition was presented eight times: six two-tone stimuli and two one-tone stimuli. Only the responses on the six two-tone stimuli were used to estimate the continuity threshold. The continuity threshold is the condition for which 50% of the times the two-tone stimulus is perceived as a single tone and 50% as two tones.

It sometimes happened that at very low tone levels a hearing-impaired subject could not hear the tone; he had to guess if there were one or two tones. This effect could be taken into account because at these lower levels the subject also had to guess when the one-tone stimuli were presented. For these stimuli the responses should be "one" if they were perceived above hearing threshold. When the level was a little higher there was almost always a region where the two-tone stimuli were perceived as continuous tones. Every subject was tested the first day and was retested the second day.

The reliability of this experiment, estimated from the test and retest results, was high for both normal-hearing subjects (reliability coefficient is 0.89, N=10) and hearing-impaired subjects (reliability coefficient = 0.85, N=20).

In order to estimate the continuity threshold for each subject we averaged the test and retest results (scores) per stimulus and determined by interpolation over tone-noise periods and levels the continuity threshold. The results of all twenty hearing-impaired listeners are incorporated in the average score of Fig. 8. The results for the 10 normal-hearing subjects are also plotted in this diagram. For both groups the continuity threshold drops to lower tone- burst levels for larger tone-noise periods. The transition range between the perception of continuity and of discontinuity appeared to be significantly larger (P < 0.01) for the hearing-impaired than for the normal-hearing listeners.

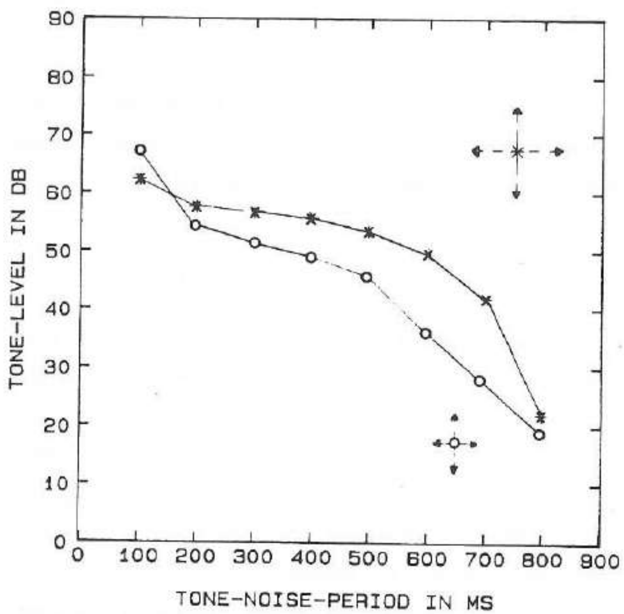


Fig. 8. Average continuity threshold curves for 10 normal-hearing (o) and twenty hearing-impaired subjects (*). The bars represent the mean standard deviations for the two groups.

As the described experiments, by which we tried to find the continuity threshold, are in close connection with the temporal characteristics of the auditory process, we also tried to relate these results to temporal-resolution measurements with the same hearing-impaired and normal-hearing subjects.

In these temporal-resolution measurements the subjects were presented with two successive amplitude-modulated noise bursts, with two 0.4-ms clicks (octave filtered around 1000 Hz) in two successive peaks or troughs of one of the noise bursts. Masked thresholds in peak and trough were determined for modulation frequencies of 5, 10, and 15 Hz in a two-alternative forced-choice method. From the level difference the width of the temporal window was calculated (more details in Festen and Plomp, 1981). This window is an indication for the temporal detection capacity of the auditory system of the subject. The results of the normal-hearing subjects showed a spread in the temporal window from 3 to 7 ms, which is in accordance with the results of earlier experiments of Festen and Plomp (1981). The spread in the temporal window for the hearing-impaired subjects was much larger: from 3 to 18 ms, which means that most impaired subjects need a slower fluctuation of auditory stimuli to extract the same temporal information than normal-hearing subjects. This result is in agreement with Festen and Plomp (1983). We can expect that the results of this experiment are related with the results of the continuity-threshold experiment because of the fact that in both cases the subject was confronted with a temporal change in the presented auditory stimulus. For this reason we compared the continuity threshold with the window measure. A significant correlation was found for tone-noise periods between 200 and 500 ms with a maximum (r=0.69) for 400 ms (the higher the level the less resolution).

e. <u>Discussion and conclusions</u>

One of the most important results of the second continuity-threshold experiment is: the very good reliability of this new method indicates that it is a very good technique to measure the continuity threshold.

Other conclusions of Experiment 2 are: for the normal-hearing as well as for the hearing-impaired subjects the continuity threshold drops to lower tone-burst levels for larger tone-noise periods; the range of the transition between the perception of continuity and of discontinuity is larger for the hearing-impaired than for the normal-hearing listeners;

finally there is a strong relation between the continuity threshold and the temporal resolution of the ear.

The results for the hearing-impaired listeners show higher values of the continuity threshold than for the normal-hearing listeners. However, the continuity-threshold levels are closer to the pure-tone threshold for the hearing-impaired listeners than for the normals. As the standard deviations of the results are large, because of the transition region in the perception of the dynamic sound stimuli, it is not possible to give an exact calculation of the differences in sensation level of the continuity thresholds for both groups of subjects.

In general the results of Experiment 2 agree with a study of Thurlow and Elfner (1959), who investigated for normal-hearing listeners the continuity effect for two alternating pure tones with durations shorter than 100 ms and different frequencies. The parameters in their research were the sound-pressure levels of the tones and the alternation periods. For most subjects the continuity effect was present when the sound-pressure level of the louder tone was about 15 dB higher than the level of the other tone and when the alternation period was larger than 80 ms but less than 1000 ms, and the frequency distance of the tones was less than about one octave.

Also close connection consists between our experiments and the experiments of Elfner and Homick (1966). They investigated various conditions under which continuity is perceived in a longer, less intense stimulus (noise) alternating with a shorter, more intense stimulus (pure tone). It was found that the duration of the noise and the frequency of the tone show significant effects on the continuity thresholds (comparable to the results of our experiments). Another study which reports related results is the one of Thurlow and Erchul (1978). When they alternated in time a low-intensity stimulus A with a high-intensity stimulus B of relatively short duration, stimulus A was heard as continuous. The level differences between A and B must be more than 5 dB but in most cases more than 10 dB to reach continuity. For large frequency differences and large tone durations the continuity effect disappears.

It can be concluded that the continuity effect exists not only for normal-hearing but also for hearing-impaired listeners. The differences between the results for the two groups of subjects for the parameters investigated in this study (i.e. tone-noise period, tone level and type of tone stimulus) are very small. However, hearing-impaired listeners perceive continuity in conditions that normals hear pulsation (for equal SPL).

CHAPTER 3

MASKING OF SHORT NOISE PROBES BY FREQUENCY SWEEPS

(appeared in modified form in De Laat and Plomp, 1986)

Summary

Smoorenburg and Coninx (1980) investigated the masking of short narrow-band noise bursts with a constant frequency by longer tone bursts with a sweeping frequency. One of the most remarkable results of their study was that, up to certain sweep speeds, the masked threshold appeared to be higher than the threshold found for stationary maskers. The aim of the present experiment was to investigate whether this behaviour found for normal-hearing listeners can also be observed for hearing-impaired listeners. Those subjects have problems in understanding speech, being a fluctuating sound, especially against a background of noise. This might suggest that for those subjects short probe stimuli can be masked even more easily. The results show that for the hearing-impaired subjects the masked threshold was maximal at a sweep speed of 25 oct/sec and on the average 21 dB higher than for stationary maskers (0 oct/sec). This sweep speed is lower, and the threshold elevation is higher than for normal-hearing listeners.

3.1 INTRODUCTION

Smoorenburg and Coninx (1980) investigated the masking of short narrow-band noise bursts with a constant frequency (< 40 ms) by longer tone bursts (< 1000 ms) with a sweeping frequency. Frequency was swept exponentially with time, and unidirectionally. Probe sounds were presented in the time center of the masker at the center frequency of the masker. One of the most remarkable results of their study was that, up to certain sweep speeds, the masked threshold appeared to be higher than the threshold found for stationary maskers. This is in contradiction with current masking theories based on detection of energy increments in critical bands. An increase in loudness of the masker, however, could be understood on the basis of an effect of bandwidth on loudness and the assumption of an integration mechanism for loudness (Nabelek, 1979). The aim of the present experiment was to investigate whether this behaviour found for normal-hearing listeners can also be observed for hearing-impaired listeners. Those subjects have problems in understanding speech, being a fluctuating sound, especially against a background of noise. This might suggest that the masking effect of short probe sounds is even greater for those people. In quiet, their speech-reception threshold (SRT) rises to higher values with respect to normal-hearing listeners due to a combined effect of attenuation and distortion of the speech stimulus. But in noisy conditions the SRT may differ up to 10 dB which is mainly an effect of distortion of the stimulus.

3.2 EXPERIMENT

a. Method

First, the pure tone threshold was measured for 19 frequencies at 1/3-octave intervals from 125 Hz to 8000 Hz. We used an adaptive Békésy procedure which takes about 20 minutes per ear.

Subsequently, the masking of short probe sounds by tone bursts with a sweeping frequency was measured. Probe sounds were narrow-band noise bursts, obtained by passing a 10-ms burst of white noise with a Gaussian time envelope through a 1/3-octave filter. The center frequency of the 1/3-octave filter was equal to the center frequency of the masker: 1 kHz. The masker was a tone burst with a single frequency component that was swept upwards. Masker onset and offset were cosine-shaped to reduce audible switching clicks. Masker duration was 100 ms or 50 ms; onset and offset times were 10 ms. The probe sound was presented at the moment that the masker passed 1 kHz. Frequency (f) was swept exponentionally with time so that log(f) varied linearly. The exponentional sweep was chosen in view of logarithmic frequency coding by the ear for most of the frequency range. It implies a constant sweep speed in octaves per second (oct/sec). The masker signal was computed using the formulae adopted from Smoorenburg and Coninx (1980). With this parameter choice (noise probe, upward sweep, masker duration of 50 ms and 100 ms, center frequency of probe and masker 1000 Hz, and probe duration 10 ms) we expected to reach most reliable results according to Smoorenburg and Coninx (1980). The stimulus configuration is schematized in Fig. 1.

Masked thresholds were measured with an adaptive two-alternative forced-choice paradigm, starting with a probe level at which the probe was clearly audible for all sweep speeds. For each hearing-impaired subject the levels of the masker and the probe were always more than 10 dB above hearing threshold. The procedure converges to an average probe level

corresponding to 79% correct response probability.

b. Apparatus

The experiments were controlled by computer. Subjects were situated in an anechoic chamber and listened monaurally by headphone (Beyer DT 48). Each condition was measured twice on different days.

c. Subjects

The subjects were 20 pupils of a highschool for the hearing impaired. Their age varied from 14 to 17 years. Their hearing loss was sensorineural. As reference group we used 10 normal-hearing pupils of the same average age and at the same educational level as the impaired subjects. The subjects took part in the experiments during two days for about 5 hours per day. No experiment lasted more than 20 minutes after which the subject could rest for about 20 minutes.

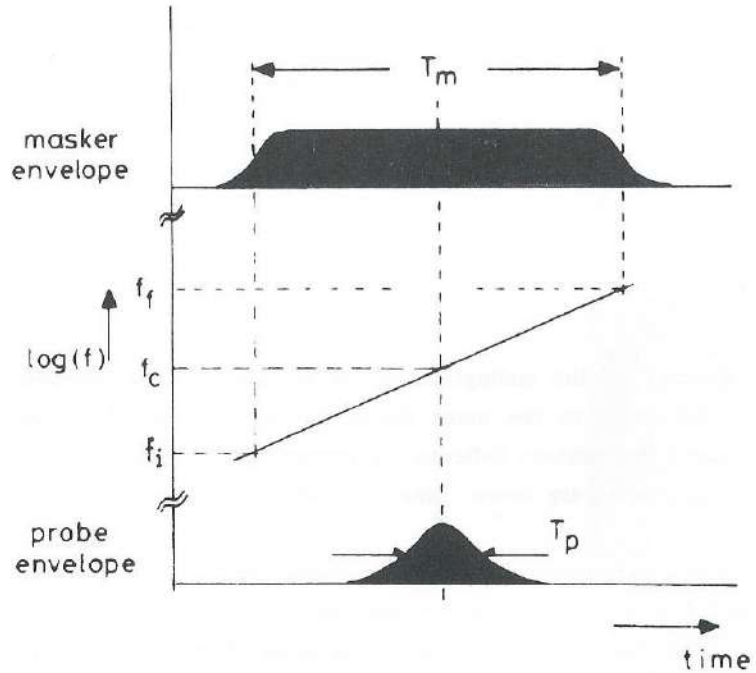


Fig. 1. Stimulus configuration. The upper part shows the masker amplitude, the middle part the masker frequency, and the lower part the probe amplitude as a function of time.

3.3 RESULTS

In Fig. 2 the distribution of the hearing thresholds of the hearing-impaired subjects is shown. The numbers indicate the percentage of subjects whose hearing levels were better than the indicated values. The subjects show an increasing hearing loss towards the higher frequencies.

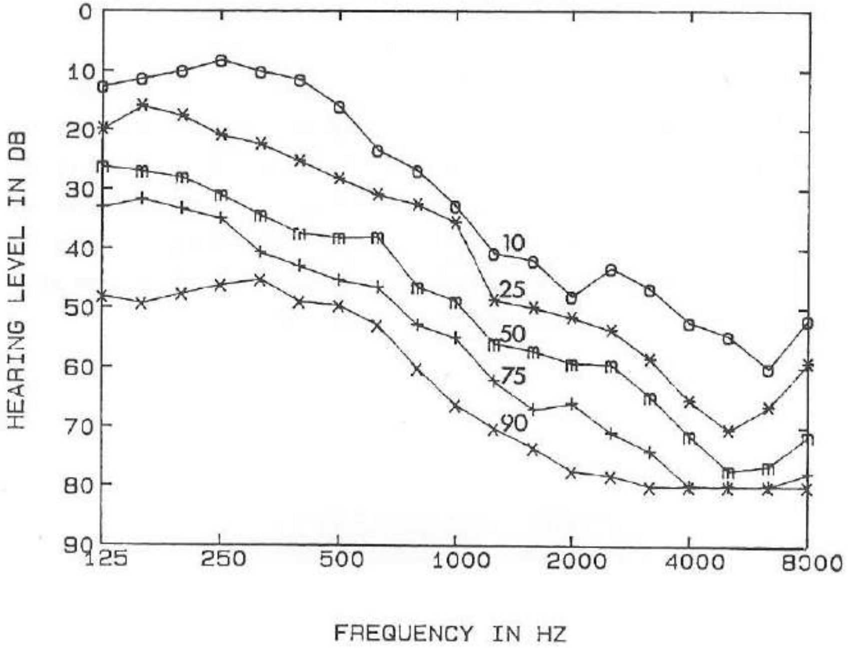


Fig. 2. Distribution of the audiograms of 20 hearing-impaired listeners with reference to the mean levels for the 10 normal-hearing listeners. The numbers indicate the percentage of subjects whose hearing levels were better than the indicated values.

Figure 3 gives the mean slope of the audiogram as a function of the mean audiometric loss for each subject individually. As can be seen, the group of 20 subjects had a great variability in slope of the audiogram as well as in mean audiometric loss. As usual (Dreschler and Plomp, 1980, 1985; Festen and Plomp, 1981, 1983) we have used these measures for correlation with the other data.

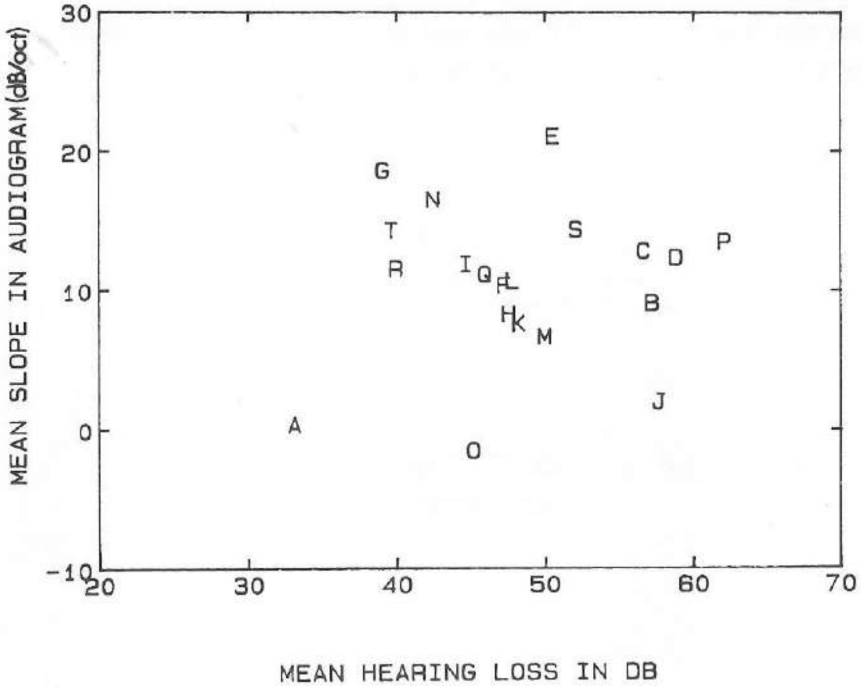


Fig. 3. Mean slope and mean audiometric loss for 20 hearing-impaired subjects (individually indicated by uppercast symbols).

For normal-hearing listeners we found that the masked threshold of a short 1/3-octave noise probe increased if the frequency of a tonal masker was swept. The sweep speed was an important parameter: the increase in masking reached a maximum value at a sweep speed of 40 oct/sec and resulted in an about 18 dB higher threshold than the masked threshold found for the stationary masker (0 oct/sec). In the upper panel of Fig. 4 the average results of these subjects are plotted separately for a masker duration of 100 ms and 50 ms, respectively.

In some respects our results differ from the results of Smoorenburg and Coninx (1980); in their experiments the masked threshold was maximal at a sweep speed of 30 oct/sec and it was about 12 dB higher than the masked threshold for the stationary masker. In addition, their masked threshold decreased slightly above 30 oct/sec. The intra-individual standard deviation was less than 4 dB in each condition, whereas the inter-individual standard deviation was about 6 dB in each condition. Smoorenburg and Coninx (1980) reported an average threshold of -15 dB for stationary maskers, whereas we found that normal-hearing subjects have an average threshold of -2 dB, but this has mainly to be attributed to the fact that Smoorenburg and Coninx used another reference value (criterium) for the level of the masker and the probe.

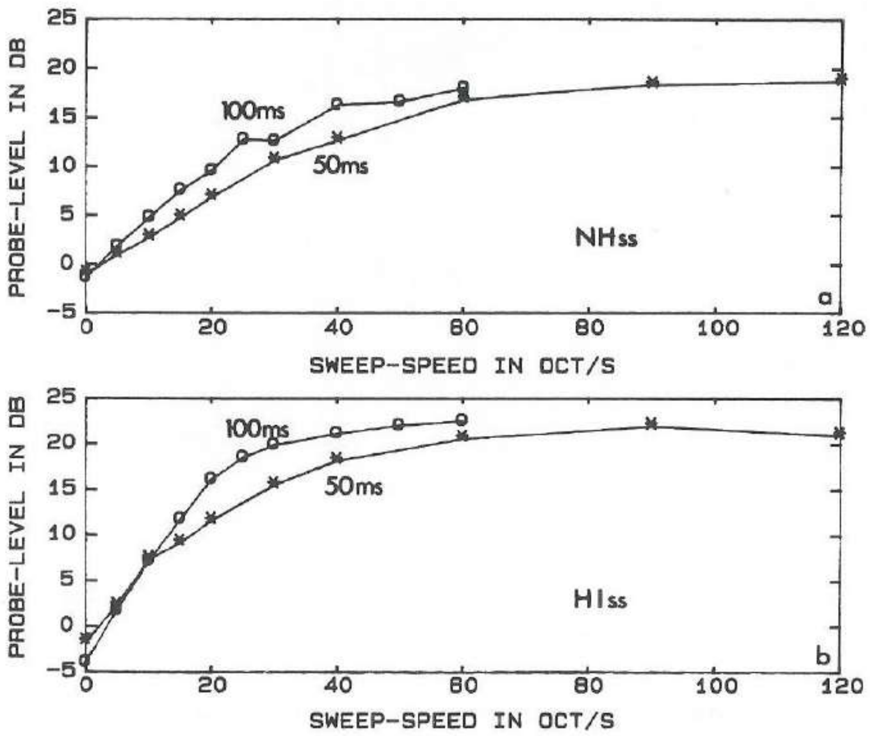


Fig. 4. Masked threshold as a function of sweep speed. The threshold level at which the probe sound is just detected is given in dB relative to the masker level. The masker was presented at 70 dB SPL, center frequency 1000 Hz, duration 100 ms and 50 ms, respectively; probe duration 10 ms. In panel a the average data for 10 normal-hearing subjects and in panel b the average data for 20 hearing-impaired subjects are presented.

Figure 4 also shows the average results for the hearing-impaired listeners, for both durations of the sweeping masker. On the average there are two main differences with respect to the results of the normal-hearing subjects: the masked threshold reached a maximum value at a sweep speed of 25 oct/sec (masker duration 100 ms) and 40 oct/sec (masker duration 50 ms) and the masked threshold was on the average 21 dB higher than the masked threshold found for the stationary masker. The intra-individual standard deviation (6 dB) was higher for the hearing-impaired subjects than for the normal-hearing subjects, and the interindividual standard deviation was much higher (15 dB).

Although, for some subjects, the masked threshold decreased slightly above 50 oct/sec, the data do not allow us to generalize this finding.

3.4 DISCUSSION AND CONCLUSIONS

As mentioned before, the main finding of the present experiment is an increase in masked threshold of short probe stimuli if the frequency of the tonal masker is swept up to certain sweep speeds. This increase is even greater for hearing-impaired than for normal-hearing subjects. This may be related to the fact that in hearing-impaired subjects different sounds have less outspoken character, poorer identity, and are more easily confused.

However, these results are inconsistent with current models of masking (e.g. Zwicker and Feldtkeller, 1967): sweeping the frequency increases the masked threshold, wheras the energy within the critical band at the probe frequency decreases.

Smoorenburg and Coninx (1980) mentioned the following: (1) the increase in masked threshold cannot be understood from models based on detection of energy increments in critical bands: when the masker passes through the critical band shorter than the integration time, a decrease of masker energy in the critical band tuned to the probe sound has to be expected; (2) a higher loudness is found for a short tone burst when its frequency is swept over a range exceeding the critical bandwidth (Coninx and Smoorenburg, 1976); according to Nabelek (1979) this effect of bandwidth on loudness and the additional assumption of an integration mechanism for loudness with a time constant of about 50 ms or more can explain the increasing effect of masking; (3) some of the effect may result from off-frequency detection.

We correlated the maximum threshold difference between the sweeping and stationary masker (in dB) with the average loss (only little correlation) and also with the mean slope in the audiogram. For sweeps of 50 and 100 ms, respectively, these correlation coefficients are -0.65 and -0.78, respectively. This means that tone bursts with a sweeping frequency have less masking effect for subjects with a high slope in the audiogram around 1000 Hz. This is understandable, because these subjects have nearly normal pure-tone thresholds for the lower frequencies, whereas higher frequencies in the sweeping masker would be less audible.

THE EFFECT OF COMPETING MELODIES ON MELODY RECOGNITION

(appeared in modified form in De Laat and Plomp, 1985)

Summary

For a group of 30 hearing-impaired subjects and a matched group of 15 normal-hearing subjects (age range 13-17) the following data were collected: the tone audiogram, the auditory bandwidth at 1000 Hz, and the recognition threshold of a short melody presented simultaneously with two other melodies, lower and higher in frequency, respectively. The threshold was defined as the frequency distance required to recognize the test melody. It was found that, whereas the mean recognition threshold for the normal-hearing subjects was five semitones, it was, on the average, 27 semitones for the hearing-impaired subjects. Although the interindividual spread for the latter group was large, the recognition threshold did not correlate with auditory bandwidth, nor with musical experience or education.

4.1 INTRODUCTION

In previous research in our group (e.g. Festen and Plomp, 1983; Dreschler and Plomp, 1985), data on different auditory functions were correlated with the speech-reception threshold in quiet and in noise, both for normal-hearing and hearing-impaired listeners. It was found that the effect of hearing impairment on speech perception can be explained partly as a result of a deterioration in the ear's frequency-resolving power. Since frequency resolution also plays an important role in music perception, it appeared worthwhile to investigate the degree to which recognition in polyphonic music is affected by hearing impairment. Hearing-impaired people often complain of difficulties in hearing when there are competing speech messages; the present study may be considered as the analogy of this condition with simultaneous tone sequences rather than voices.

Several studies are known about the auditory capacity of normal-hearing subjects to segregate two or more fluctuating tone sequences. Experiments by Bregman (1972) indicated that most subjects were able to detect changes in the temporal pattern of two melodies if the rate was below 5 tones per second. Van Noorden (1975) compared temporal coherence, fission, and fusion in the perception of tone sequences. The temporal coherence boundary depends heavily upon the tone rate; the fission boundary, however, is relatively independent of the tone rate.

Studies by Deutsch (reviewed in Deutsch, 1982) included tone and melody recognition. Only rare individuals are able to reproduce or recognize a single tone, in spite of our daily exposure to a multitude of such tones. In contrast, most of us easily learn to recognize and recall tonal combinations such as melodies. No experiments on the effect of hearing impairment on melody recognition are known to the present author.

In addition to melody recognition, the auditory bandwidth of the subjects was measured in our experiments. We can expect that subjects with wide critical bands, due to hearing impairment, will have difficulties in discriminating simultaneous tones in a musical context, which will be detrimental to the perception of melodies in polyphonic music.

Many authors have examined frequency selectivity, frequency discrimination, hearing loss, and speech intelligibility in noise. Some important conclusions can be drawn from the studies by Florentine et al. (1980), Zurek and Formby (1981), Hall and Fernandes (1983), Tyler et al. (1982, 1983), Festen and Plomp (1983), and Dreschler and Plomp (1985): Frequency selectivity is reduced in the frequency range of a cochlear hearing loss, this reduction is almost independent of sound level.

In our experiments, melody recognition was studied by means of sequences of three simultaneous tones, in which the frequency distance between these tones required to perceive correctly the melody of the middle tones was the criterion.

4.2 EXPERIMENTS

a. Method

First, the pure-tone hearing level was measured at 11 frequencies (125, 250, 500, 630, 800, 1000, 125 , 1600, 2000, 4000 and 8000 Hz). We used an adapted Békésy procedure, which takes about 10 min per ear.

Subsequently, the melody-recognition limit was investigated. The subject had five push buttons at his disposal. Three of the push buttons activated (1) the test melody alone, (2) the test melody presented simultaneously with two masking melodies, and (3) an alternative melody, again presented simultaneously with the two masking melodies (see Fig. 1). These masking melodies were at equal distances (in semitones) below and

above the test melody. The two response buttons corresponded to the two masking situations.

The melodies consisted of four pure tones. The subject was allowed to hear each of the three signals twice, after which he had to decide which of the two complex signals contained the test melody. The test melody was always in the frequency region around 500 Hz. The alternative melody was equal to the test melody, except that the second and third notes were in reversed order (this restriction was not known to the subject). In this way, with the critical notes in the test melody surrounded both in time and frequency by other notes, we tried as much as possible to make the subject use melody difference as a criterion. The two masking melodies were at a variable frequency distance above and below the test melody.

The distance of the tones within any melody was never greater than three semitones, with no repeated tones in the same melody. All 24 possible variations in ordering four tones with no repeated tones were presented at random. From experiments by van Noorden (1975) we may conclude that the tone sequences used were always within the temporal coherence boundary.

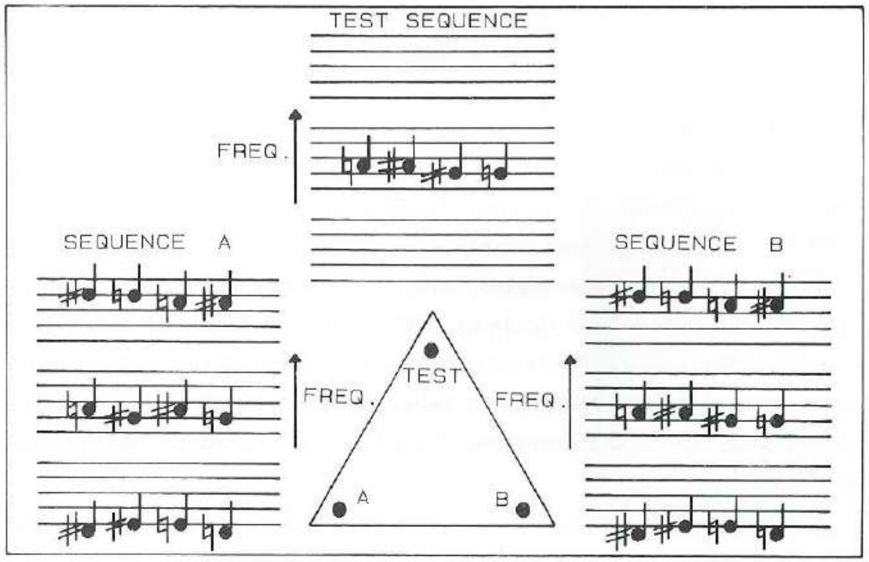


Fig. 1. Example of the procedure used in the melody-recognition experiment.

Tone duration was 350 ms, with silent intervals between the tones of 50 ms, resulting in a rate of 2.5 tones per second. Bregman (1972) found that a melody with a small pitch range, separated from the range of the interleaved background, is easily perceived at rates from 1.4 to 20.0 tones per second.

The tones were gated with rise and fall times of 15 ms, and their frequencies were chosen according to the equal-tempered scale. Octave relations between tones of the test melody, the alternative melody, and the masking melodies were avoided. Octaves are more likely to fuse such that the individual components are less audible as single tones (e.g. Bregman and Doehring, 1984). So when a note in a masking melody has an octave relation with a note in the test melody, this may disturb its recognition. The melodies were presented at a constant, most comfortable sound level.

The minimum frequency distance between the test melody and the masking melodies required to recognize correctly the middle melody was measured with an adaptive two-alternative forced-choice procedure. The starting value was a distance of 45 semitones between test melody and masking melodies. After three successive correct responses the distance was decreased by two semitones and after each wrong response the distance was increased by the same amount. In this way a threshold distance was reached corresponding to a probability of a correct response of 79%. The test lasted 15 min for long distances up to 30 min for short distances.

Finally, the auditory bandwidth of the subjects was measured with a pocedure adopted from Houtgast (1974). A 1000-Hz probe tone was presented simultaneously with comb-filtered white noise at a spectral level of 60 dB/Hz. The detection threshold was measured both at the peak and in the valley of the noise signal, with ripple densities of 1/2, 1, and 2 ripples per 1000 Hz. From Houtgast (1974) we know that only these three ripple densities are needed to estimate the bandwidth of the auditory filter reasonably accurately. The peak-to-valley ratio was 20 dB (see Fig. 2). We used an adaptive two-alternative forced-choice procedure which takes about 30 min per ear.

In the melody-recognition test the pitches of the pure tones, which form the melodies, were around 500 Hz, i.e. the region around A4 (440 Hz). The auditory bandwidth was measured with a 1000-Hz probe tone, because this test was part of a battery of tests with tones in the region around 1000 Hz. A preliminary experiment with 10 hearing-impaired subjects (with comparable losses) indicated that the correlation coefficient between the

auditory bandwidths at 500 and at 1000 Hz was 0.89 (see also Dreschler and Plomp, 1985).

All experiments were carried out twice on different days. The experiments were preceded by a standard training scheme, after which all subjects had no problems in performing the test. For the melody-recognition test both normal-hearing and hearing-impaired listeners were able to recognize the test melody in a condition of no competing melody, after being trained.

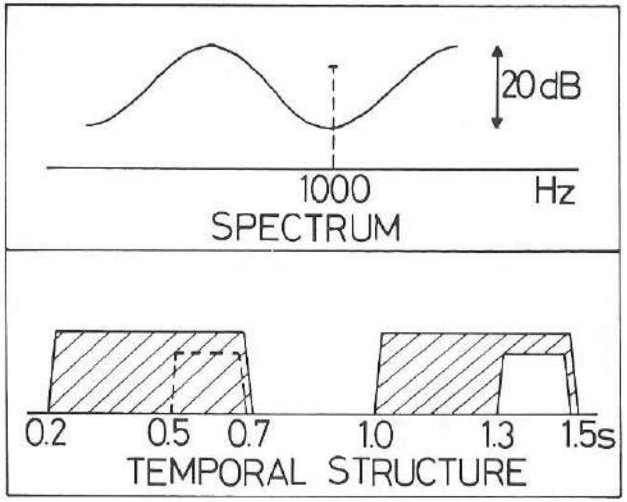


Fig. 2. Spectrum and temporal structure in the bandwidth experiment.

b. Apparatus

The experiments were controlled by computer. The subjects were situated in an anechoic chamber and listened monaurally over headphones. The tone generators, filters, gates, amplifiers, and attenuators were of standard types or made by our technical staff.

c. Subjects

As hearing-impaired subjects, 30 pupils with sensorineural hearing losses attending a high school for the hearing impaired were used. Their age varied from 13 to 17 years. As a reference group we used 15 normal-hearing pupils of the same average age and at the same educational level as the hearing-impaired subjects. The subjects were partly the same pupils as the listeners to the experiments described in previous chapters. In the melody-recognition test and in the auditory-bandwidth test only one ear of the subject was used: the ear with the smaller mean audiometric loss. All subjects were paid for their services.

4.3 RESULTS

The distribution of the hearing thresholds of the hearing-impaired subjects is shown in Fig. 3. The numbers indicate the percentage of subjects whose hearing levels were better than the indicated values. The subjects show an increasing hearing loss towards the higher frequencies.

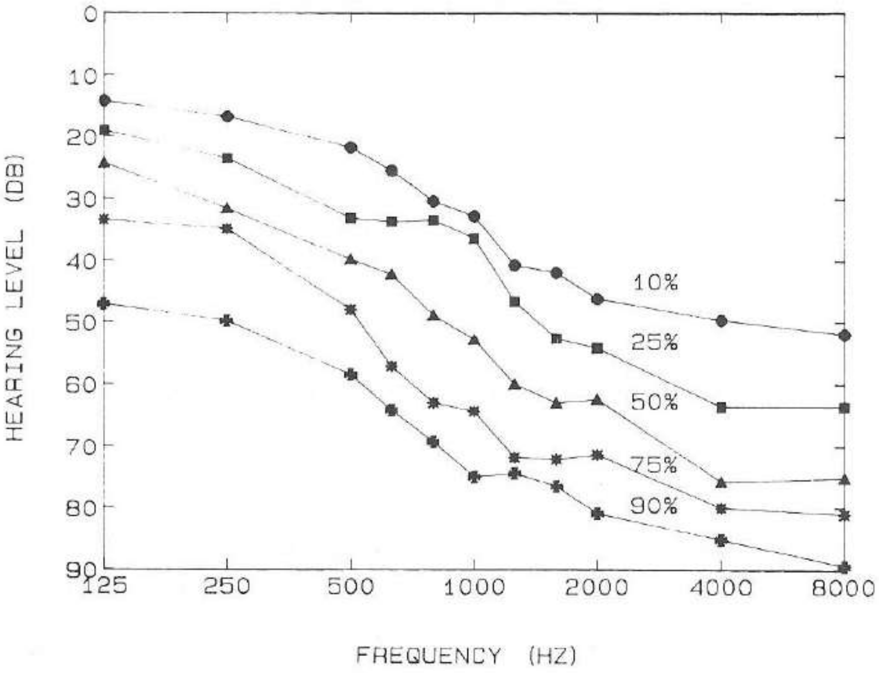


Fig. 3. Distribution of the audiograms of 30 hearing-impaired listeners with reference to the mean levels for the 10 normal-hearing listeners. The numbers indicate the percentage of subjects whose hearing levels were better than the indicated values.

Figure 4 gives, for each subject individually, the mean audiometric loss as a function of the mean slope in the audiogram. As can be seen, the group of 30 subjects had a great variability, both in the mean slope and in the mean loss. In the same way as Dreschler and Plomp (1980), we have used these measures for correlation with the other data.

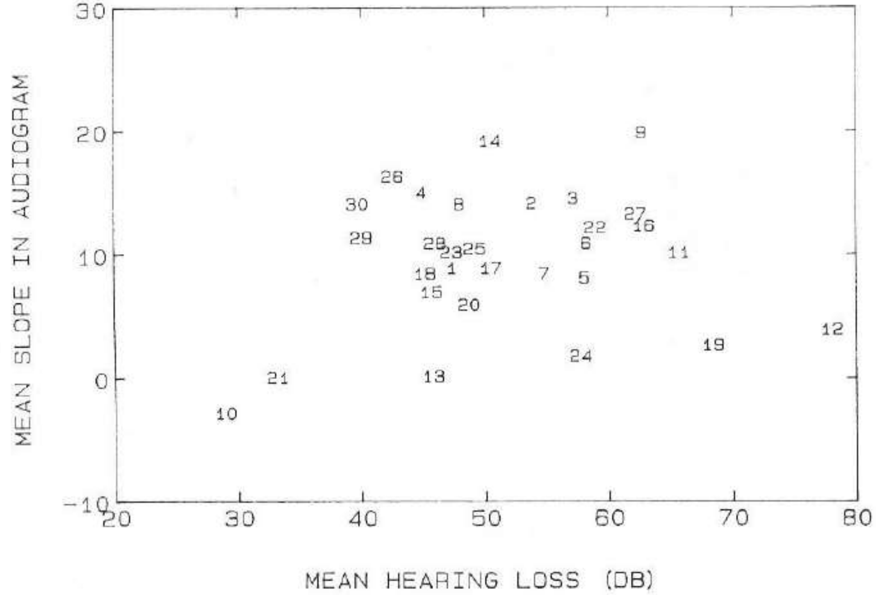


Fig. 4. Mean slope vs. mean audiometric loss for the 30 hearing-impaired subjects.

In Figs. 5 and 6 the results of the melody-recognition test are plotted. Figure 5 represents the frequency-distance threshold of the test melody for the hearing-impaired subjects both in the test and in the retest. The test-retest reliability is very good. The reliability coefficient for the hearing-impaired subjects is 0.91. There was no significant learning effect.

Histograms of these thresholds are presented in Fig. 6. The mean threshold for the normal-hearing subjects is 5 semitones (standard deviation 3 semitones) and the mean threshold for the hearing-impaired subjects is 27 semitones (standard deviation 10 semitones). Apparently there is a large difference between the two groups.

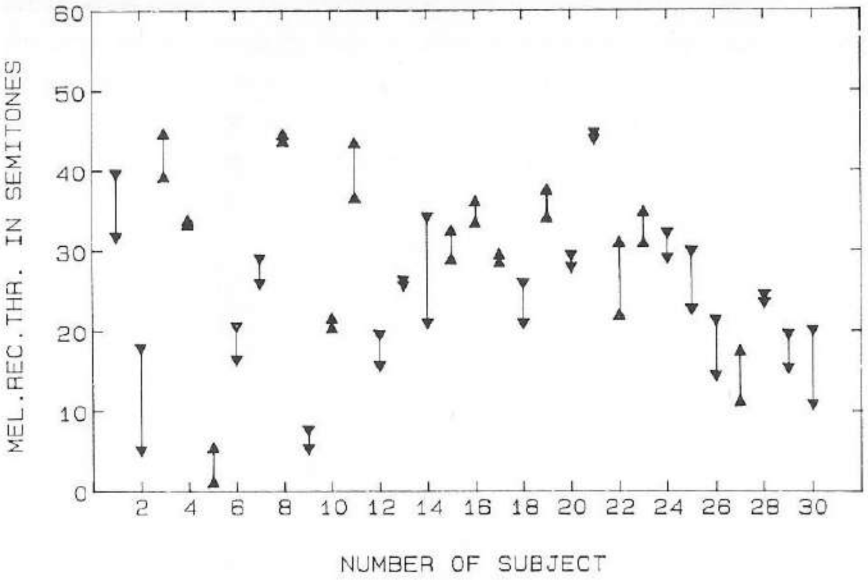


Fig. 5. Recognition threshold of masked melodies for the 30 numbered hearing-impaired subjects in test and in retest, according to the direction of the arrow.

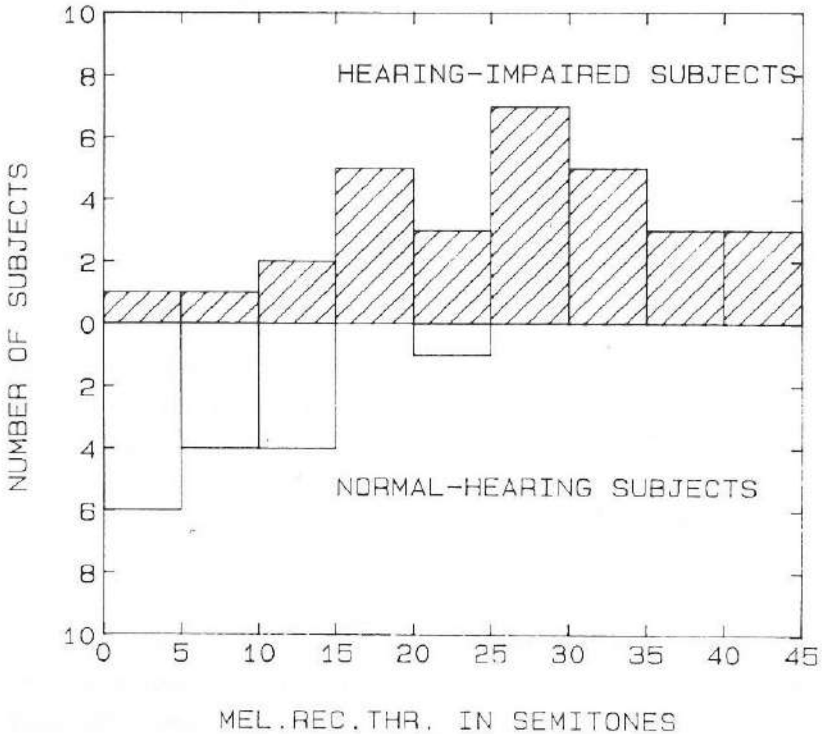


Fig. 6. Recognition threshold of masked melodies in histogram form.

In the scatter diagram of Fig. 7 the auditory-bandwidth data for the hearing-impaired subjects are combined with the thresholds found in the melody-recognition test. On the basis of the hypothesis that the ear's frequency selectivity is a constitutive factor in melody recognition, we expected a correlation between the results of the two tests. The correlation coefficient actually found for the 30 hearing-impaired subjects was, however, only 0.23 and not significant. The correlation coefficient for the 10 hearing-impaired subjects with the auditory bandwidth measured at 500 Hz instead of 1000 Hz was 0.34, and also not significant.

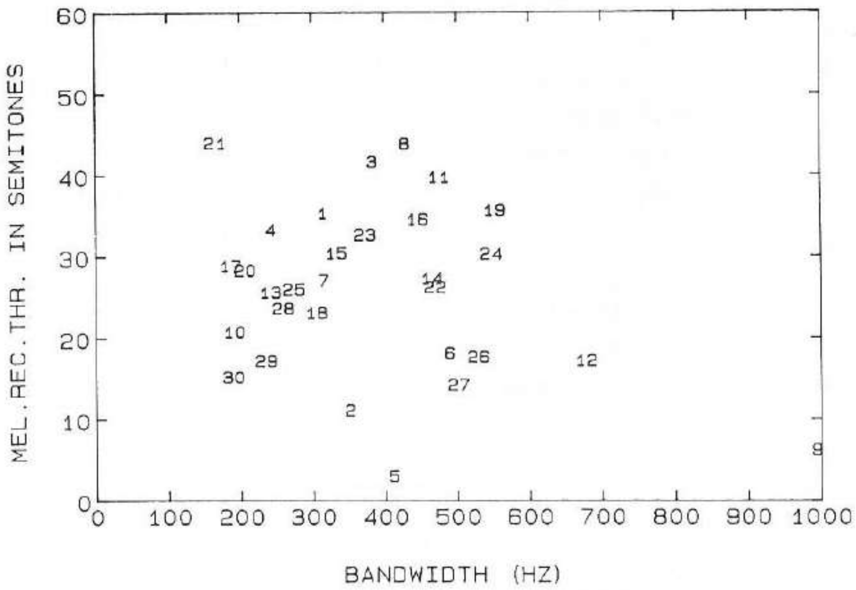


Fig. 7. Recognition threshold of masked melodies in semitones as a function of the logarithm of the auditory bandwidth (at 1000 Hz), for the 30 hearing-impaired subjects.

The results of the melody-recognition test do not correlate any better with other auditory functions measured, like mean hearing loss, mean slope in the audiogram, and temporal resolution. It is apparent that some hearing-impaired subjects with relatively wide auditory bandwidths are very good at recognizing melodies, and that on the other hand some hearing-impaired subjects with relatively narrow auditory bandwidths hardly recognize the melodies.

4.4 DISCUSSION AND CONCLUSIONS

The finding that for the hearing-impaired listeners the melody-recognition threshold around 500 Hz was not correlated with the bandwidth measured around 1000 Hz, is rather surprising.

It suggests that other factors, more centrally located than peripheral frequency selectivity, were responsible for the fact that these subjects performed much worse than normal-hearing listeners of the same age and at the same educational level.

A possible explanation might be that, due to their hearing loss, the subjects were not so experienced at listening to music, so that the experimental task of melody recognition was much more difficult for them than for the normal-hearing subjects. In order to get some insight into this question, we requested 20 of the 30 hearing-impaired subjects to listen to a recording of "Peter and the Wolf" by S. Prokofiev. After that, a part of the composition in which seven different instruments are prominent was played again, and the subjects were asked to recognize these instruments.

In Fig. 8, for 20 hearing-impaired subjects (with numbers 1 to 20), the number of instruments recognized is plotted as a function of the mean recognition threshold of masked melodies. Apparently, the two scores are not related.

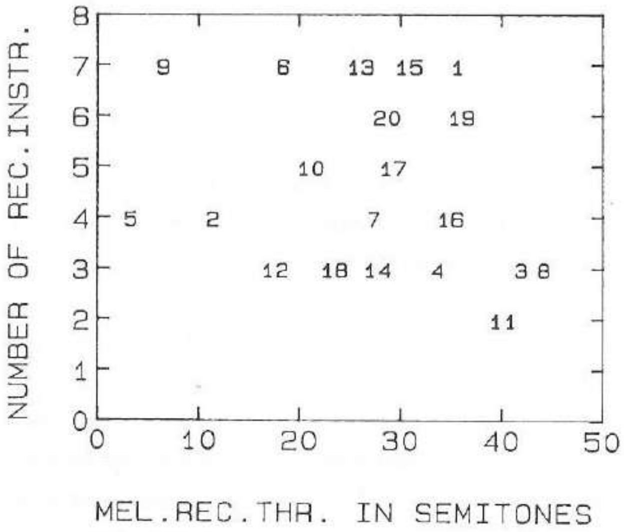


Fig. 8. **Number of recognized instruments as a function of the recognition threshold of masked melodies for 20 hearing-impaired subjects.**

We also asked the subjects whether they liked listening to music or played an instrument. A relation between these answers and the test performances could not be found. So there is no evidence that an interest in music improves the results of the melody-recognition test.

We may conclude that hearing-impaired subjects show a considerable spread in their ability to recognize a melody presented simultaneously with two melodies lower and higher in frequency. This reduced ability appears not to be correlated with the auditory bandwidth of the impaired ear, nor with the subject's musical experience or education.

CHAPTER 5

THE PERCEPTION OF PLOSIVE CONSONANTS

(abstract appeared in De Laat and Plomp, 1984b)

Summary

Reduced speech perception by hearing-impaired subjects has often been studied. In order to investigate the role of co-articulation we did some experiments on a group of 25 hearing-impaired and 10 normal-hearing subjects. From 45 embedded CVCVC words we deleted either the plosive bursts, or the vocalic CV or VC transitions, or the stationary vowel portions, or any combination of these four. The listeners were asked to identify the three plosive consonants in the resulting stimuli. The results for the normal-hearing subjects agree with results of Schouten and Pols (1983): Identification is affected more by deletion of plosive bursts than of vocalic transitions, and in medial consonants the CV transition contains more information about the consonant than the VC transition does. For the hearing-impaired listeners the vocalic transitions play a more important role: identification with the plosive bursts only results in guessing. In contrast with the results for the normal-hearing subjects, more errors occur for the final consonant than for the initial or the medial consonant.

5.1 INTRODUCTION

Relations between hearing impairment and reduced speech-perception capacity, compared with frequency selectivity and temporal resolution, have been studied by several investigators (Reed, 1975; Bilger and Wang, 1976; Walden et al., 1980; Dreschler and Plomp, 1980, 1985).

Revoile et al. (1982) investigated the perception of consonants (C) for both normal-hearing and hearing-impaired listeners. They concluded that identification of voiced consonants and differentiation between voiced and unvoiced consonants is influenced by the perception of the transition between vowel (V) and consonant.

Many authors studied the perception of the transition between vowel and consonant in normal hearing. Fujimura et al. (1978) and Streeter and Negro (1979) concluded that consonant-vowel (CV) transitions are more important than vowel-consonant (VC) transitions for intervocalic plosive consonants. Sharf and Ohde (1981), however, found that CV transitions in word-initial plosive consonants are less important than VC-transitions in word-final plosive consonants.

Klaassen-Don (1983) gave more detailed information: the initial part of the vowel transition in CV syllables and the final part in VC syllables do contain some information about the adjacent consonants. She stated that perceptual information in the vowel transition about the contiguous consonant is often redundant for normal-hearing subjects. Parker (1974) also found that voicing distinction for final stops could be cued by differences in the end portion of the preceeding vowels. Dorman et al. (1977) wrote that the relative importance of bursts and transitions depends on the particular combination of consonant and vowel. Schouten and Pols (1983) did similar experiments and investigated the relative contributions of bursts and transitions in initial, medial and final positions, by deleting either the one or the other. They found that the identification of the consonant is affected more by deletion of the plosive burst than of the vocalic transition.

Godfrey and Millay (1978) and Florentine et al. (1980) did experiments with hearing-impaired people and found that even moderate hearing loss sometimes causes abnormal reception of transitions. Reduced frequency selectivity could affect discrimination of the spectral cues in speech. Pickett et al. (1972) showed that voicing perception depended partly on the degree of hearing loss.

We focussed our attention upon some of the mentioned co-articulation aspects, but now for hearing-impaired subjects in addition to a group of normal-hearing subjects. In order to investigate the role of co-articulation by studying the relative contributions of bursts and transitions in initial, medial and final positions, we repeated the experiments by Schouten and Pols (1983) for groups of hearing-impaired as well as normal-hearing subjects as a reference.

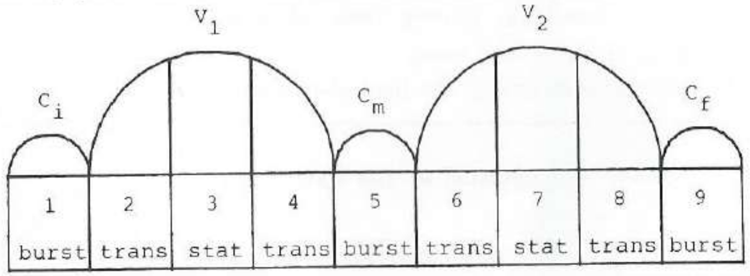
5.2 EXPERIMENTS

a. Procedure

Meaningless CVCVC words (consonant-vowel-consonant-vowel-consonant) were presented to the listeners. In this experiment each of three combinations of vowel and consonant (-CV, VCV, VC-) occurred. The vowels were chosen from 12 monothongs and 3 diphthongs and were presented in random order. The initial and medial plosive consonants were

/p/, /t/, /k/, /b/ or /d/ and the final plosive consonants were /p/, /t/ or /k/. The CVCVC words were embedded in carrier phrases: leading word, target word (CVCVC word), and final word. To avoid "interference", the leading word ended with a vowel or /r/ ("luister", "attentie", "noteer", "versta") and the final word started with a vowel or /s/ ("stop", "einde", "over", "uit"). The CVCVC-words were split up into nine segments (Fig. 1).

According to the rules for segmentation (Table 1) 13 stimulus conditions could be formed, varying from the complete undisturbed word to disturbed words with deletions (cutting out) of bursts, transitions, stationary parts of the vowel or combinations (Fig. 1).



segment nr 1	2	3	4	5	6	7	8	9	stim nr	description
+	+	+	+	+	+	+	+	+	1	complete signal
-	+	+	+	-	+	+	+	-	2	1 minus all bursts
+	-	+	-	+	-	+	-	+	3	1 minus all transitions
-	-	+	-	-	-	+	-	-	4	stationary vowels only
-	-	+	+	-	-	+	+	-	5	stat. vowels & VC trans. only
+	-	+	+	+	-	+	+	+	6	1 minus CV transitions
-	+	+	-	-	+	+	-	-	7	CV trans. & stat. vowels only
+	+	+	-	+	+	+	-	+	8	1 minus VC transitions
+	+	-	+	+	+	-	+	+	9	1 minus stationary vowels
-	+	-	+	-	+	-	+	-	10	transitions only
+	-	-	-	+	-	-	-	+	11	bursts only
+	-	-	+	+	-	-	+	+	12	bursts & VC trans. only
+	+	-	-	+	+	-	-	+	13	bursts & CV trans. only

Fig. 1. The upper part gives detailed information about the segmentation of the CVCVC word, the lower part contains detailed information about the 13 conditions with the segmentation criteria.

segment 1	*The burst partition of the first plosive consonant*
segment 2	*The CV transition, starting immediately after the burst, including the first three pitch periods of the first vowel*
segment 3	*The stationary part of the first vowel*
segment 4	*The VC transition, starting three pitch periods before the ending of the first vowel*
segment 5	*The burst partition of the second plosive consonant*
segment 6	*The CV transition, starting immediately after the burst, including the first three pitch periods of the second vowel*
segment 7	*The stationary part of the second vowel*
segment 8	*The VC transition, starting three pitch periods before the ending of the second vowel*
segment 9	*The burst partition of the final plosive consonant*

Table 1. Rules for segmentation of the CVCVC words.

Every CVCVC word was embedded in a carrier phrase. For every stimulus condition 45 carrier phrases were formed. This means that, before segmentation, each of the five initial consonants occurred nine times, each of the five medial consonants nine times as well, each of the three final consonants 15 times, and each of the 15 vowels (the first as well as the second vowel) occurred three times in the 45 presentations of the CVCVC word.

The speech material, adopted from Schouten and Pols (1983), was spoken by a native Dutch male speaker and digitally recorded (sample frequency 12.5 kHz). Presentation was controlled by computer. The phrases were presented at a most comfortable level. The subjects were situated in an anechoic chamber and listened monaurally over headphones. The subjects responded by hitting the consonant buttons of a computer keyboard.

One full list of 45 phrases without deletions was presented to the listener to get acquainted to the experiment. Each phrase was presented only one time to the subject. For the initial and medial consonants the subject could only push the buttons of the consonants p, t, k, b or d. For the final consonant only the buttons of the consonants p, t or k were at his disposal. After presentation of one stimulus and the response of the subject the next stimulus was presented (without information about whether the response was correct or not). After one list of 45 phrases the subject was informed about his result (total number of correct responses)

to keep him/her motivated.

The subject was tested on two days: two hours on the first day for half of the material, and two hours on the second day for the other half. The reliability of the scores was determined by comparison of the results for the phrases 1 to 22 with the results for the phrases 24 to 45.

The tests were performed monaurally by earphone for the ear with the lower hearing level averaged over 500, 1000 and 2000 Hz.

b. Subjects

The experiments were carried out with a group of 25 pupils (all of them aged between 13 and 17) of a highschool for the hearing impaired. Figure 2 shows the distribution of their hearing levels, which were of sensorineural origin. Ten young normal-hearing people (of the same average age and at the same educational level as the hearing-impaired listeners) took part in the experiments as well. All subjects had participated in former psychophysical experiments and were paid for their services.

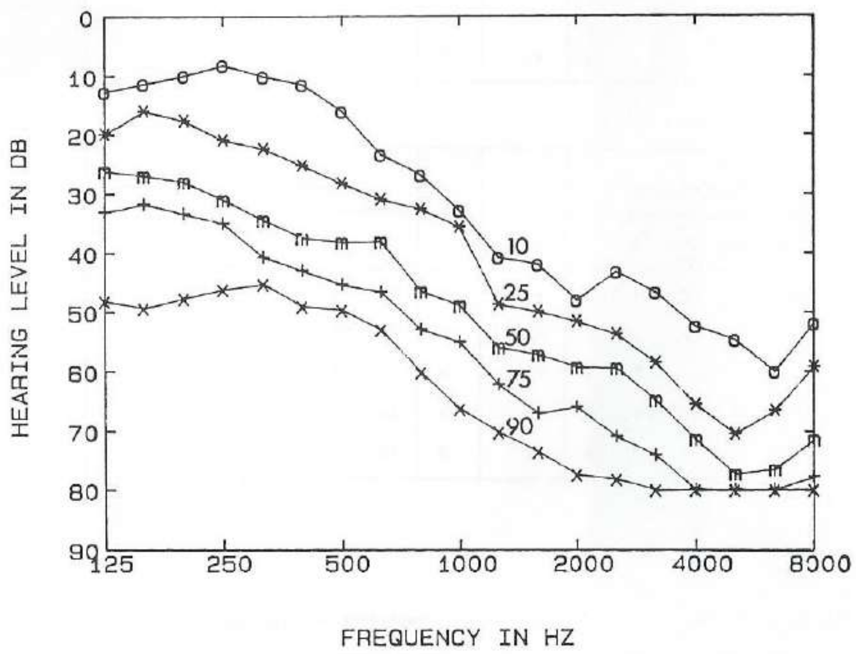


Fig. 2. Distribution of the audiograms of 25 hearing-impaired listeners with reference to the mean levels for the 10 normal-hearing listeners. The numbers indicate the percentage of subjects whose hearing levels were better than the indicated values.

5.3 RESULTS

For all thirteen stimulus conditions, separate confusion matrices were derived, cumulated over all hearing-impaired or normal-hearing listeners. Such a confusion matrix shows the scores for either the initial, the medial or the final plosive consonants in the disturbed CVCVC words.

As an example Table 2 presents the confusion matrices for the initial consonant for stimulus condition 1 (complete signal) and for stimulus condition 11 (only bursts present).

a	RESPONSE p	t	k	b	d	% corr.
p	81	1	5	3	0	90
t	1	81	5	1	2	90
k	1	1	88	0	0	98
b	1	0	0	86	3	96
d	0	7	0	1	82	91

b	RESPONSE p	t	k	b	d	% corr.
p	127	24	32	29	13	56
t	43	107	52	12	11	48
k	13	10	192	6	4	85
b	2	0	2	174	47	77
d	6	7	2	64	146	65

a	RESPONSE p	t	k	b	d	% corr.
p	47	8	20	13	2	52
t	14	58	5	4	9	64
k	12	2	69	6	1	77
b	5	1	0	75	9	83
d	8	3	3	20	56	62

b	RESPONSE p	t	k	b	d	% corr.
p	59	15	67	62	22	26
t	51	51	61	40	22	23
k	27	10	137	30	21	61
b	28	13	16	144	24	64
d	32	18	28	111	36	16

Table 2. The upper part shows the cumulated confusion matrices for the initial consonant of all normal-hearing subjects (a) and all hearing-impaired subjects (b) for stimulus condition 1 (complete signal). The lower part shows the confusion matrices for stimulus condition 11 in which the transitions and the stationary parts of the vowels were deleted.

We averaged the results for the unvoiced and for the voiced consonants, respectively. The percentages of correct responses for all thirteen stimulus conditions for the initial, medial and final plosive consonant are gathered in Table 3.

No.	stimulus condition	c_i unvoiced	c_i voiced	c_m unvoiced	c_m voiced	c_f unvoiced
1	complete signal	*63* 93	*71* 93	*67* 97	*68* 98	*60* 96
2	1 minus all bursts	*27* 37	*37* 42	*44* 64	*45* 76	*51* 70
3	1 minus all trans.	*47* 76	*58* 79	*53* 82	*50* 80	*54* 88
4	stat. vowels only	*26* 25	*28* 34	*33* 49	*23* 25	*40* 47
5	stat. vowels & VC trans. only	*27* 24	*22* 42	*40* 54	*22* 49	*44* 68
6	1 minus CV trans.	*49* 80	*55* 84	*59* 93	*54* 92	*58* 93
7	CV trans. stat. vowels only	*29* 33	*38* 52	*37* 55	*27* 55	*43* 52
8	1 minus VC trans.	*61* 86	*68* 93	*62* 91	*61* 91	*56* 90
9	1 minus stat. vowels	*52* 87	*64* 88	*50* 90	*57* 92	*57* 92
10	trans. only	*23* 31	*22* 32	*36* 51	*31* 52	*44* 60
11	bursts only	*37* 64	*40* 73	*31* 49	*32* 56	*40* 66
12	bursts & VC trans. only	*40* 70	*49* 78	*39* 76	*39* 72	*49* 89
13	bursts & CV trans. only	*52* 87	*58* 89	*50* 69	*47* 82	*46* 85

Table 3. Average percentage of correct responses for initial, medial and final consonants for the thirteen stimulus conditions for 25 hearing-impaired subjects (in italics) and 10 normal-hearing subjects.

As can been seen in Tables 2 and 3, the scores for the normal-hearing subjects for stimulus condition 1 (complete signal) are almost 100%. The average scores for the hearing-impaired listeners are lower than 100%; the range of the scores is large enough to differentiate between the various stimulus conditions. For stimulus condition 4, the worst case for the consonants, the average score of the hearing-impaired listeners approaches chance level (20% for both initial and medial consonants, 33.3% for final consonants), while for normals the values are 5-30% higher than chance level.

Fig. 3 contains for the hearing-impaired listeners the graphic presentation of the scores of Table 3 for the final consonant (left) and the initial consonant (right). From the center of the figure the stimulus conditions are arranged such that, theoretically, the information of the stimulus presented to the subject reduces in the left-hand direction for the final consonant and in the right-hand direction for the initial one. The stimulus conditions are grouped together according the categories which will be mentioned in Tables 4 and 5.

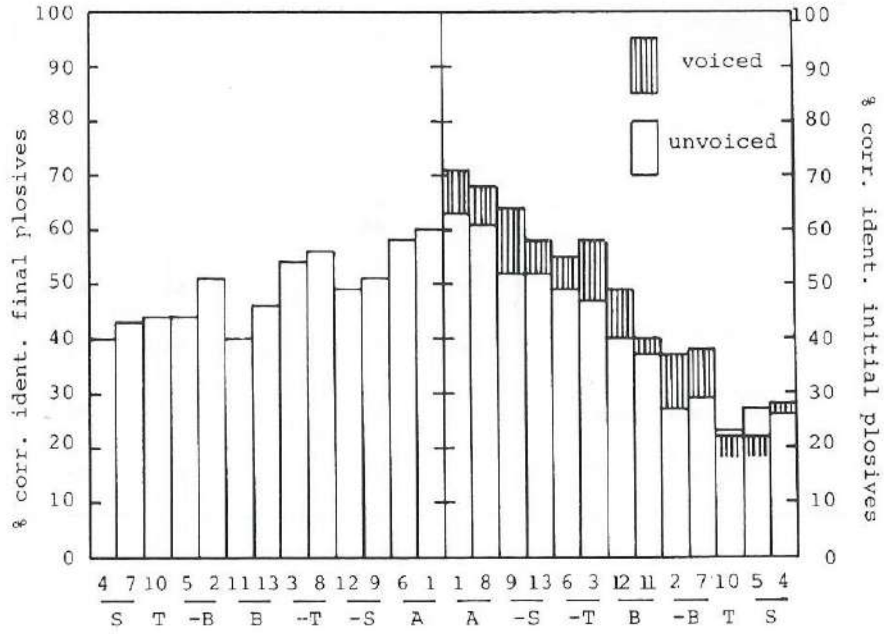


Fig. 3. **Average percentage of correctly identified final and initial consonants for the hearing-impaired listeners. For the meaning of S, T, B, etc., see Table 4.**

Fig. 4 shows the results for the medial consonant for the hearing-impaired subjects. From the center of the figure to the left the results for the VC transition are shown, from the center to the right the results for the CV transition. In this manner, this figure can easily be compared with Fig. 3.

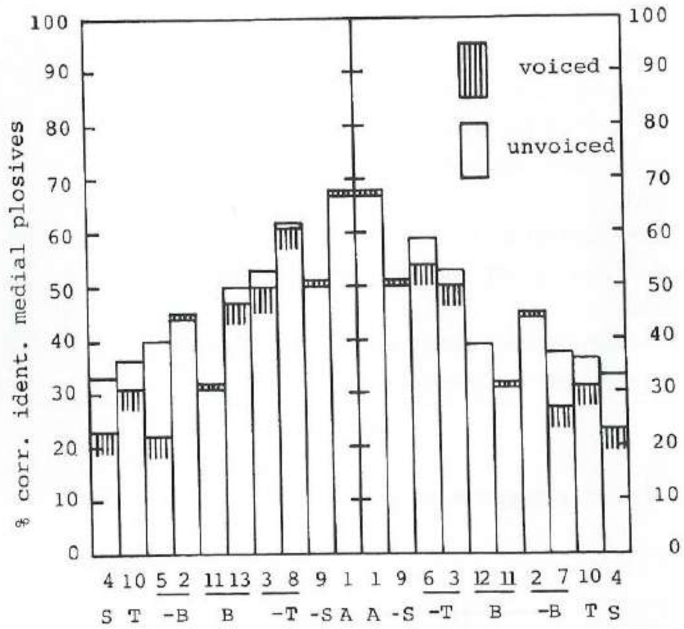


Fig. 4. **Average percentage of correctly identified medial consonants for the hearing-impaired listeners (to the left: VC transitions, to the right: CV transitions). For the meaning of S, T, B, etc., see Table 4.**

For the initial plosive consonant only stimulus conditions 11 and 12 contain information about the burst with both the CV transition and stationary part of the vowel deleted. For the final consonant only stimulus conditions 11 and 13 do similarly, for the medial consonant 3 and 11. We combined these conditions and called the new category: B (only the burst partition of the plosive consonant is present). In this way seven different combination categories of stimulus conditions can be formed (Table 4).

Table 5 shows the combinations which form the seven categories for initial, medial and final plosive consonants. The stimulus conditions for the medial consonant are divided into two groups which appear in two columns

(VC and CV). These columns only differ for the categories -T (transition deleted), B (only burst partition present), and -B (burst partition deleted); in these cases the presence of both the VC transition and CV transition differ. In this way the results for the medial consonant (VC) can easily be compared with the results for the final consonant and the results for the medial consonant (CV) can easily be compared with the results for the initial consonant (Figs. 3 and 4).

A	*The complete signal without deletions*
-S	*The stationary part of the vowel deleted from the complete signal*
-T	*The transition between consonant and vowel deleted from the complete signal*
B	*Only the burst partition of the plosive consonant present*
-B	*The burst partition of the plosive consonant deleted from the complete signal*
T	*Only the transition between vowel and consonant present*
S	*Only the stationary part of the vowel present*

Table 4. Seven different categories of stimulus conditions.

	INIT.	MED. (VC)	MED. (CV)	FIN.
A	1 & 8	1	1	1 & 6
-S	9 & 13	9	9	9 & 12
-T	3 & 6	3 & 8	3 & 6	3 & 8
B	11 & 12	11 & 13	11 & 12	11 & 13
-B	2 & 7	2 & 5	2 & 7	2 & 5
T	10	10	10	10
S	4 & 5	4	4	4 & 7

Table 5. Conversion from thirteen stimulus conditions into seven categories referring to the presence of burst partition, transition between vowel and consonant and stationary part of the vowel.

For the initial and medial consonants, choice had to be made between p, t, k, b or d and for the final consonant between p, t or k. As we like to compare the results for on the one hand the initial and medial consonants and on the other hand the final consonant, we can divide the results for the initial and medial into two groups: the results for the voiced consonant (b and d) and for the unvoiced consonant (p, t, and k). For the initial and medial consonants, the chance level is 20% (five alternatives) and for the final consonant the chance level is 33.3% (three alternatives).

Table 6 comprises the percentages of average correct responses for the normal-hearing and hearing-impaired listeners, for initial, medial and final, voiced and unvoiced consonants for all seven combination categories of stimulus conditions, ordered according to the quantity of information expected to be present in the stimulus.

id.	stimulus condition	c_i unvoiced	c_i voiced	c_m unvoiced	c_m voiced	c_f unvoiced
A	complete signal	*62* 89	*70* 93	*67* 97	*68* 98	*59* 94
-S	A minus stat. vowels	*52* 87	*61* 89	*50* 90	*51* 92	*50* 91
-T	A minus trans.	*48* 78	*57* 82	*53* 82	*51* 80	*55* 89
B	burst only	*39* 67	*45* 76	*42* 49	*41* 56	*43* 75
-B	A minus bursts	*23* 35	*38* 47	*40* 64	*38* 76	*48* 69
T	trans. only	*23* 31	*22* 32	*39* 51	*25* 52	*44* 60
S	stat. vowels only	*27* 25	*25* 38	*33* 49	*23* 25	*42* 50
	chance level	20	20	20	20	33

Table 6. Percentage of correct responses for initial, medial and final, voiced and unvoiced plosive consonants for seven combination categories of stimulus conditions for 25 hearing-impaired listeners (in italics) and 10 normal-hearing listeners.

Fig. 5 shows the graphic presentation of the percentages correctly identified final and initial unvoiced plosive consonants for all seven categories of stimulus conditions for the normal-hearing as well as for the hearing-impaired people.

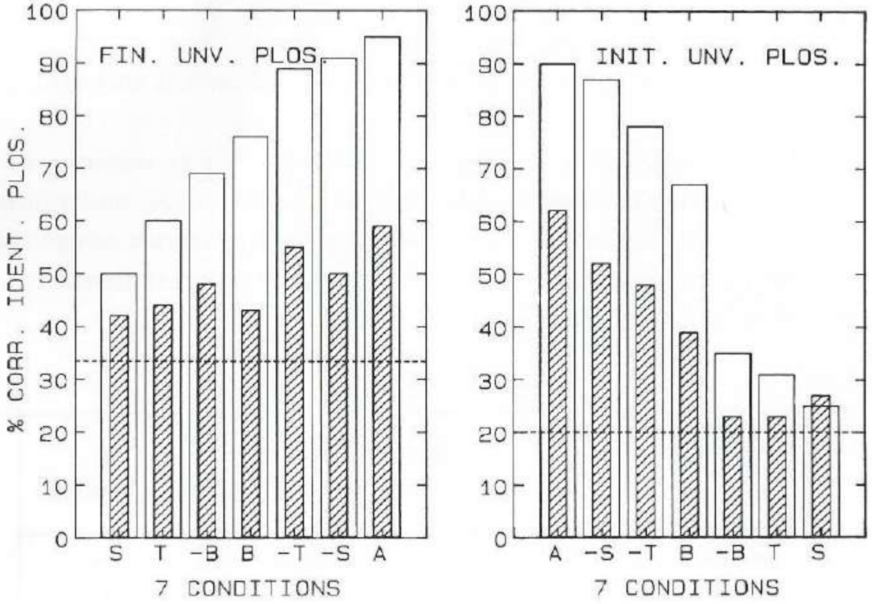


Fig. 5. Percentage of correctly identified final and initial unvoiced plosive consonants for seven combination categories of stimulus conditions for both normal-hearing subjects (white bars) and hearing-impaired subjects (shaded bars).

Fig. 6 shows the percentages of correctly identified medial (VC) and medial (CV) unvoiced plosive consonants for all seven categories of stimulus conditions for normal-hearing as well as for hearing-impaired people.

The responses in the case of the medial (VC) unvoiced plosive consonants are related to the VC transition and the responses in the case of the medial (CV) unvoiced plosive consonants are related to the CV transition. Only the bars for condition "-T" (transition between vowel and consonant deleted) and "T" (transition between vowel and consonant present only) are different from each other for medial (VC) and medial (CV) consonants. In this way the results of Fig. 5 can easily be compared with the results of Fig. 6.

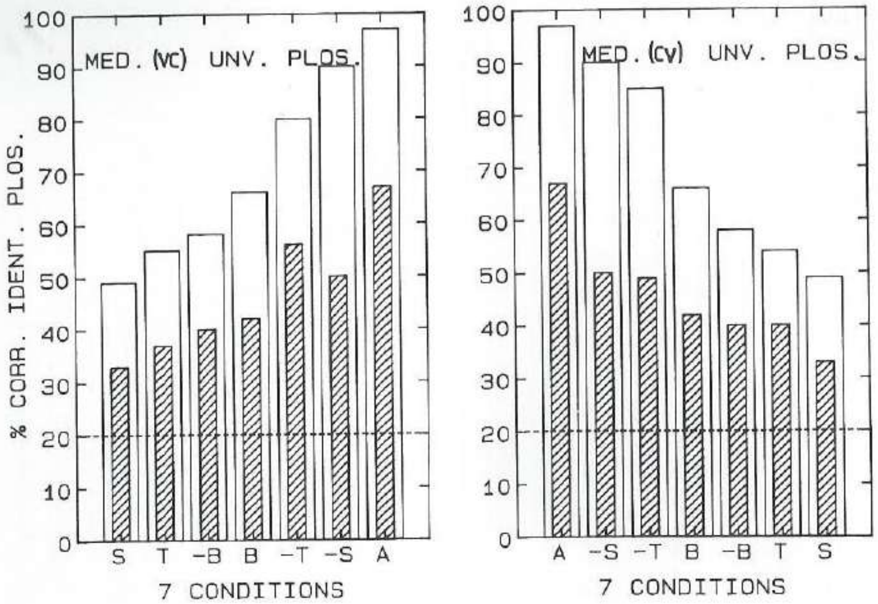


Fig. 6. Percentage of correctly identified medial (VC) and medial (CV) unvoiced plosive consonants for seven combination categories of stimulus conditions for both normal-hearing subjects (white bars) and hearing-impaired subjects (shaded bars).

Fig. 7 shows the percentages of correctly identified medial (VC) and medial (CV) voiced plosive consonants for all seven categories of stimulus conditions for the normal-hearing as well as for the hearing-impaired people. The responses in the case of the medial (VC) voiced plosive consonants are related to the VC transition and the responses in the case of the medial (CV) voiced plosive consonants are related to the CV transition.

As is well known, hearing-impaired subjects use lip-reading for better understanding. In case of lip-reading, no difference can be made in the perception of two different consonants, which have the same place of articulation, like t and d, p and b. To see whether hearing-impaired as well as normal-hearing subjects generally benefit from the different sound cues from one pair to the other, we also checked the scores of correctly identified plosives for both normal-hearing and hearing-impaired listeners, if only attention has been paid to the place of articulation. So the differences between p and b and also between d and t are neglected.

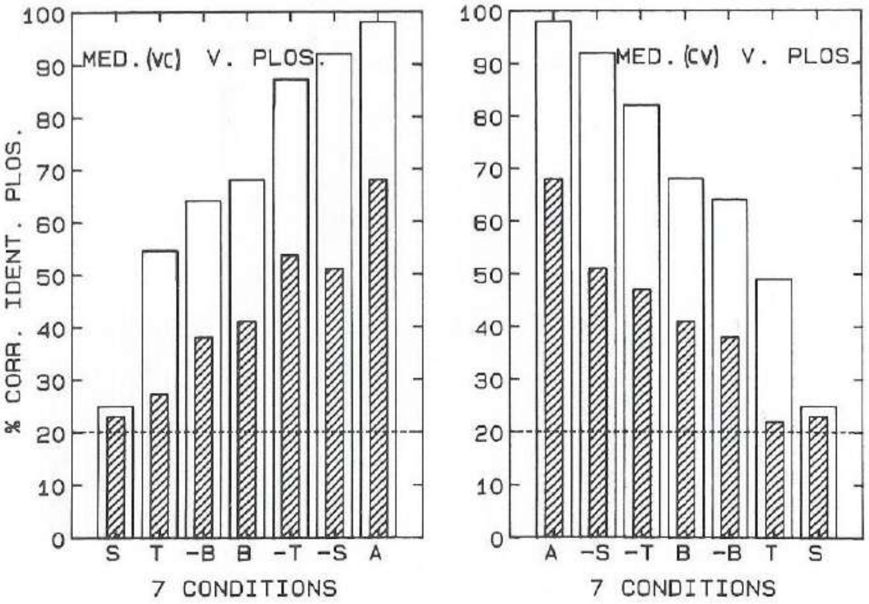


Fig. 7. Percentage of correctly identified medial (VC) and medial (CV) voiced plosive consonants for seven combination categories of stimulus conditions for both normal-hearing subjects (white bars) and hearing-impaired subjects (shaded bars).

These scores for all combination categories of stimulus conditions are indicated in Table 7.

5.4. DISCUSSION AND CONCLUSIONS

Attention will be paid to the differences between normal-hearing and hearing-impaired subjects, including the results for initial, medial and final consonants, voiced and unvoiced consonants, the role of the place of articulation and the importance of the different parts of the stimulus (burst partition, transition between vowel and consonant, stationary part of the vowel). Only those differences which are significant ($P < 0.05$) will be mentioned.

For all conditions the scores for the hearing-impaired listeners are lower than the scores for the normals, which means that sensorineural hearing-impairment affects the perception of consonants.

id.	stimulus condition	c_i unvoiced	c_i voiced	c_m unvoiced	c_m voiced	c_f unvoiced
A	complete signal	*69* 93	*72* 96	*71* 99	*72* 98	*59* 94
-S	A minus stat. vowels	*60* 90	*64* 90	*58* 95	*57* 94	*50* 91
-T	A minus trans.	*53* 81	*61* 84	*57* 88	*60* 85	*55* 89
B	burst only	*49* 74	*54* 80	*53* 59	*51* 68	*43* 75
-B	A minus bursts	*34* 45	*63* 75	*48* 76	*58* 90	*48* 69
T	trans. only	*33* 43	*46* 59	*54* 64	*41* 69	*44* 60
S	stat. vowels only	*36* 39	*50* 54	*41* 56	*49* 49	*42* 50
	chance level	33	40	33	40	33

Table 7. Percentage of correct responses for initial, medial and final voiced and unvoiced plosive consonants for seven combination categories of stimulus conditions for 25 hearing-impaired listeners (in italics) and 10 normal-hearing listeners: p/b and d/t confusions are neglected.

The scores were lower for the subjects with larger hearing losses, but the scores were lowest for the subjects with largest slopes in the audiogram.

In general, except when the stationary part of the vowel is present (S), the percentage of correctly identified voiced medial plosive consonants is for the normal-hearing subjects comparable with the percentage of correctly identified unvoiced medial plosive consonants (Figs. 6 & 7); when only the transition between consonant and vowel is present (T) the percentage of correctly identified voiced medial plosive consonants is for the hearing-impaired subjects lower (up to 19%, $P<0.01$) than the percentage of correctly identified unvoiced medial plosive consonants (Figs. 6 & 7). This could mean that the spectral contrast in the transition between vowels and consonants is greater for unvoiced than for voiced plosive consonants for the hearing-impaired subjects. This agrees with the reduced frequency selectivity of hearing-impaired listeners.

For the hearing-impaired listeners the percentage of correctly identified voiced medial plosive consonants in cases where the burst partition has been deleted (-B) is higher (about 15%, $P<0.01$) than in cases where only the transition between vowel and consonant is present (T). This last percentage is on chance level (20%), but much higher (about 50%, $P<0.01$) for the normal-hearing subjects (Fig. 7). This result could mean that normal-hearing subjects benefit more from information about the transition between vowel and consonant than hearing-impaired listeners in cases of intervocalic consonants (less spectral contrast).

When no part of the CVCVC word has been deleted, the identification of the final consonant is worse (about 5%, $P<0.05$) than the identification of the initial consonant for the hearing-impaired subjects (Fig. 5: A(fin.) < A(init.)). This is in contrast with the results for the normal-hearing subjects. In general, for the normal-hearing subjects the percentage of correctly identified unvoiced initial plosive consonants is smaller than the percentage of correctly identified unvoiced final plosive consonants. This is not the case with the results for the hearing-impaired subjects where the percentage of correctly identified unvoiced initial plosive consonants is not smaller than the percentage of correctly identified unvoiced final plosive consonants (Fig. 5). Both results could mean that the effect of the 'sudden' initial plosive consonant, which seems to affect its recognition by normal-hearing subjects, is not applicable to hearing-impaired subjects.

In conditions where only the burst partition is present, the percentage of correctly identified plosive consonants does not differ significantly from the result in conditions where only the burst partition has been deleted (Figs. 5, 6 & 7: B ≡ -B). These percentages are above chance level. There is one exception: the percentage of correctly identified unvoiced initial plosive consonants in the situation when the burst partition has been deleted from the signal is on chance level and lower than when the burst partition is present (Fig. 5). This fact applies to hearing-impaired listeners and agrees with aspects mentioned before.

If the burst partition of the initial unvoiced plosive consonant has been deleted from the signal (also in conditions where only the transition between consonant and vowel or the stationary part of the vowel is present: -B, T, S) the results for both normal-hearing and hearing-impaired listeners are at chance level (Fig. 5), in contrast with the results for the medial and final consonant. This means that in all situations the beginning of a word (starting with a plosive consonant) is very important. Distortion at the starting point is more effective than distortion in other burst partitions of the word. This is probably due to the fact that the coarticulation effect of the initial consonant is missing.

In conditions where the burst partition has been deleted, all plosive consonants are less well identified (9% up to 26%, $P<0.01$) than in conditions where the transition between vowel and consonant has been deleted for both normal-hearing and hearing-impaired listeners (Figs. 5, 6, & 7: -B < -T). For almost all situations the identification of the plosive consonant is worse (10% up to 18%, $P<0.01$) in conditions where only the transition between vowel and consonant is present than in conditions where only the burst partition is present (Figs. 5, 6, & 7: T < B). There is, however, one exception: if the percentage of correctly identified plosive consonants, in conditions where only the transition between vowel and consonant is present, is above chance level, there is no clear difference between the conditions with only transition and with only burst partition present for hearing-impaired listeners (Figs. 5 & 6: T ≡ B). Conclusion: there is no reason to doubt that the transition between vowel and plosive consonant is less important than the burst partition to identify the plosive consonant for both normal-hearing and hearing-impaired listeners.

For both normal-hearing and hearing-impaired listeners, the percentage of correctly identified unvoiced initial plosive consonants is lower (up to 45%) than the percentage of correctly identified voiced initial plosive consonants in almost all stimulus conditions (Tables 6 & 7). This is especially the case in conditions where the burst partition has been deleted (-B) and in conditions where only the the transition between vowel and consonant is present (T). This means that the transition plays a far more important role in the identification of a voiced consonant than in the identification of an unvoiced consonant. Apparently, both normal-hearing and hearing-impaired listeners benefit from the fact that voiced initial plosive consonants "consume" a bit more time (some periods) than unvoiced initial plosive consonants (onset voicing versus silence before the burst of the consonant).

The percentage of correctly identified medial plosive consonants in cases where the CV transition has been deleted, is lower (about 7%, $P<0.05$) than in cases where the VC transition has been deleted. This applies to both normal-hearing and hearing-impaired listeners (Fig. 7: -T(CV) < -T(VC)). It can be concluded that in medial consonants, the CV transition contains more information about the consonant than the VC transition does.

In general, identification was affected more by deletion of plosive bursts than of vocalic transitions. For the hearing-impaired listeners, the vocalic transitions play a more important role: identification with plosive bursts only results in guessing. In contrast with the results for the normal-hearing subjects more errors occur for the final consonant than for the initial or the medial consonant, which is more apparent when corrected for chance (Tables 6 & 7).

CHAPTER 6

THE RECEPTION THRESHOLD OF INTERRUPTED SPEECH

(appeared in modified form in De Laat and Plomp, 1983)

Summary

In quiet the speech-reception threshold (SRT) is closely related to the pure-tone threshold. However, since hearing-impaired subjects most often complain about noisy circumstances, SRT measured in noise is more suitable to describe the handicap of those people.

In our experiments we used noise, interrupted in time or filtered in frequency, comparable to daily-life situations. It appeared that normal-hearing listeners benefit more from the silent intervals between the noise bursts to understand speech than hearing-impaired listeners. The average SRT difference between normal-hearing and hearing-impaired listeners measured in interrupted noise was 15-20 dB, whereas the average SRT difference in continuous noise was only about 3 dB. The auditory bandwidth correlated weakly with the SRT measured in filtered noise.

6.1 INTRODUCTION

Several investigations have been published on the relation between the speech-reception threshold (SRT) and different auditory functions, both for normal-hearing and hearing-impaired listeners (Dreschler and Plomp, 1980, 1985; Festen and Plomp, 1981, 1983; Lyregaard, 1982; Wightman, 1982; Moore, 1984; Rosen and Fourcin, 1986). The SRT data in these studies were obtained for stationary noise. In this paper, we will report on experiments in which the speech signal is disturbed by noise discontinuous in time or/and in frequency. The interrupted-noise conditions may give a better description of the hearing handicap of the subjects than the stationary-noise conditions, as in daily life most environmental sounds are also fluctuating. Additionally to SRT, the auditory bandwidth of the subjects was measured, according to the method of Houtgast (1974). This parameter, together with hearing level, showed the highest correlation with respect to the results of SRT measurements (Festen and Plomp, 1981).

Some authors have reported on experiments in which the intelligibility of interrupted speech by normal-hearing listeners was investigated, including the effect of added noise. In the experiments by Miller and Licklider (1950) the interruption rate was an important parameter; the highest intelligibility scores were obtained for about 10 interruptions per sec. Higgins (1975) also published the results of experiments with interrupted speech. He, too, found an optimal rate of 10 interruptions per sec. Powers and Wilcox (1979) experimented with and without intervening noise. They observed that the intelligibility is highest if the interruptions are filled with noise at about the same loudness level as the interrupted speech. As fas as is known no experiments on the intelligibility of interrupted speech by hearing-impaired subjects have been done before.

6.2 EXPERIMENTS

a. Method

First, pure-tone thresholds were measured for 11 frequencies (125, 250, 500, 630, 800, 1000, 1250, 1600, 2000, 4000, and 8000 Hz). We used an adapted Bêkésy procedure which takes about 10 min per ear.

Secondly, the speech-reception threshold (SRT) for sentences was measured in quiet and in noise. The sentences were presented in an adaptive up-and-down procedure as described by Plomp and Mimpen (1979). With a list of 13 short sentences (8 or 9 syllables), a threshold measurement can be performed with a standard deviation of approximately 1 dB for normal-hearing subjects. The noise had the same spectrum as the long-term average spectrum of the sentences. In three conditions the noise was presented continuously at a level of 65 dB(A), 75 dB(A) or 85 dB(A) respectively (indicated by C65, C75 and C85). In three filtered conditions (symbolized by F75, F85, and F95; the numbers indicate the continuous noise level), the noise was present only in the 1/3 octaves around the frequencies 125, 250, 500, 1000, 2000 and 4000 Hz. The slopes of the filters were 60 dB per octave. In three other conditions the noise was interrupted in time 10 times per sec, with a duty cycle of 50% (conditions abbreviated by T65, T75, and T85; again, the numbers indicate the continuous level).

Thirdly, the auditory bandwidth was measured with a procedure adopted from Houtgast (1974). A 1000-Hz probe tone was presented simultaneously with comb-filtered white noise at a spectral level of 60 dB/Hz (intensity in 1-Hz intervals). The detection threshold was measured both at the peak and in the valley of the noise signal, with ripple densities of 1/2, 1 and 2 ripples per 1000 Hz. From Houtgast (1974) we know that only these three ripple densities are needed to estimate the bandwidth of the auditory filter with some accuracy. We used an adaptive

two-alternative forced-choice procedure which takes about 30 min per ear.

b. Apparatus

The speech material was digitally recorded. The experiments were controlled by computer. The subjects were situated in an anechoic chamber and listened monaurally by headphone.

c. Subjects

The subjects were 20 pupils of a highschool for the hearing-impaired, aged between 13 and 17 years. Their hearing losses were sensorineural. As a reference group we used 10 normal-hearing pupils of the same average age and at the same educational level as the hearing-impaired subjects. The subjects took part in the experiments during 2 days for about 5 hours per day. No experiment lasted more than 20 minutes, after which the subject could rest for about 20 minutes.

6.3 RESULTS

The hearing-impaired subjects showed an increasing hearing loss towards the higher frequencies. Fig. 1 gives the mean slope in the audiogram as a function of the mean hearing level for each hearing-impaired subject individually, relative to the mean results of the normal-hearing subjects. As can be seen, the group of 20 subjects had a great variability in slope in the audiogram as well as in mean hearing level. In the experiments of Dreschler and Plomp (1980) these two parameters appeared to be the most important to describe the audiogram, so we have used them to correlate with the other data.

In Fig. 2 the SRT values are presented for the hearing-impaired subjects, relative to the mean results of the normal-hearing subjects. The hearing loss for speech in continuous noise (85 dB(A)) is plotted as a function of the hearing loss for speech in quiet. The hearing loss for speech in noise increases by an amount of 0 to 9 dB as the hearing loss for speech in quiet increases by an amount of about 15 to 45 dB. These numbers are in the same range as the numbers of Dreschler and Plomp (1980, 1985) and Plomp (1986).

In Fig. 2 for 10 hearing-impaired subjects also the SRT values measured one year before are shown. The differences for the hearing losses for speech in quiet vary over a range of no more than 5 dB and for speech in noise over a range of no more than 1.5 dB. This is an indication of the reliability of the test.

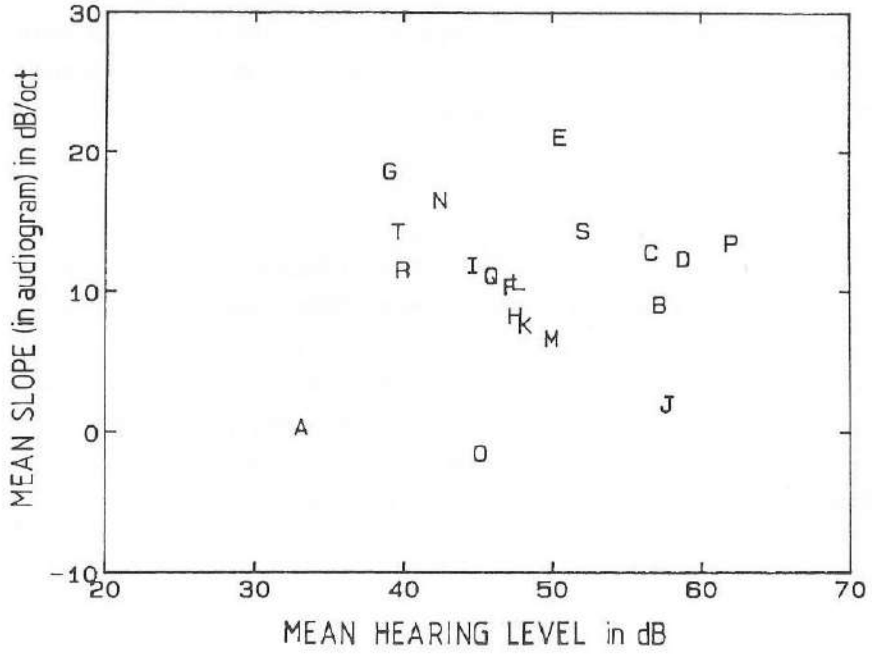


Fig. 1. **Mean slope of the audiogram and mean hearing level for the 20 hearing-impaired subjects (individually indicated by uppercast symbols).**

In Fig. 3 the average SRT values obtained in the 10 listening conditions are reproduced both for the normal-hearing and the hearing-impaired subjects.

The data for the normal-hearing subjects in quiet and in continuous noise are in agreement with the data of Plomp (1986). For the hearing-impaired subjects the average hearing loss for speech in quiet is about 34 dB, whereas the average hearing loss for speech in continuous noise is about 3 dB (Fig. 2).

The results for the three continuous-noise conditions show that SRT increases by 10 dB for an increment of 10 dB of the continuous-noise level. This increment of SRT is smaller in the conditions with interrupted noise for both normal-hearing and hearing-impaired subjects. It appears that an increment of 10 dB in noise level (duty cycle 50%) causes an increment of 7 dB in SRT for almost all listeners.

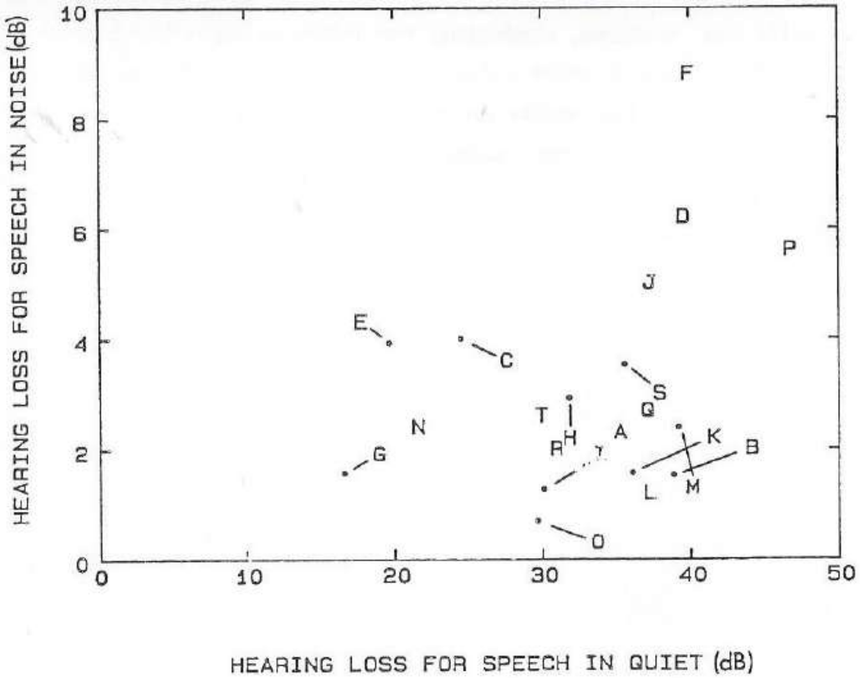


Fig. 2. **Hearing-loss for speech in noise and hearing-loss for speech in quiet for 20 hearing-impaired subjects (individually indicated by uppercast symbols). The SRT values of measurements of one year before are indicated by dots (for 10 hearing-impaired subjects).**

In the filtered-noise conditions an increase of 10 dB of the noise level causes an increase of about 11 dB of the SRT for the normal-hearing subjects, whereas the results for the hearing-impaired subjects show an increment of less than 10 dB of the SRT. This effect has to be attributed to the fact that the SRT in quiet for some subjects is only about 7 dB lower than the threshold in filtered noise.

For the hearing-impaired subjects the differences between the results of test and retest vary over a range of 5 dB for the temporal and 3 dB for the spectral interruptions. The reliability coefficient of all data points in the SRT experiment is about 0.90 for the hearing-impaired subjects.

The most important result of this experiment is the great discrepancy between normal-hearing and hearing-impaired subjects in the interrupted-noise conditions: an average difference of about 20 dB is found, whereas the average difference in the continuous-noise conditions is about 3 dB. For these conditions and for almost all listeners the pure speech-to-noise ratio was measured, eliminating the influence from the reception threshold for speech in quiet (attenuation effect): indeed, the average differences between the results for the conditions T65 and T75 and T75 and T85 have about the same values (7 dB) for both groups of listeners.

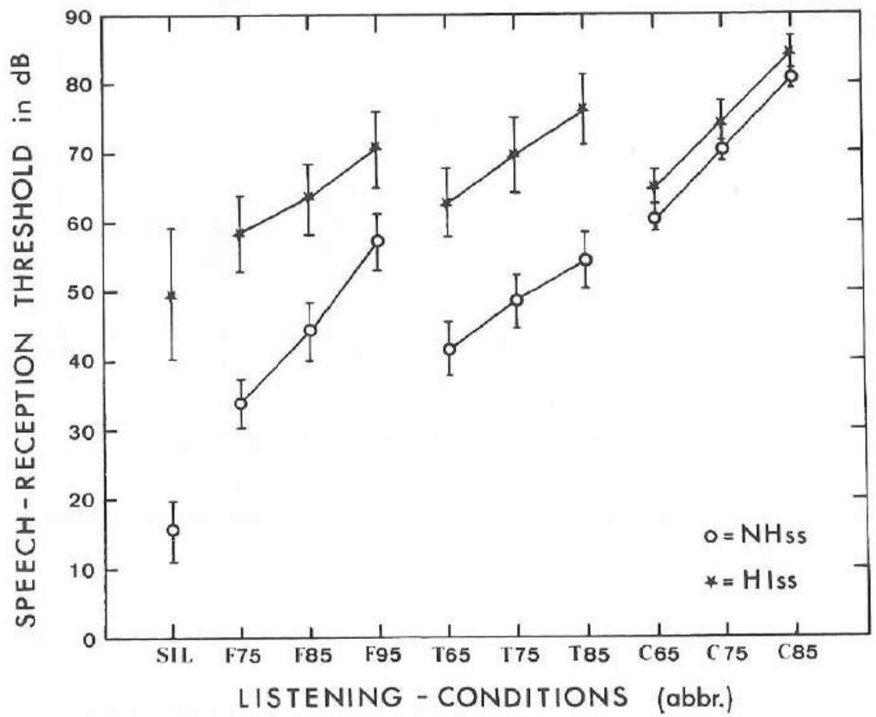


Fig. 3. Speech-reception threshold in 10 listening conditions. The open symbols represent average values for 10 normal-hearing, the cross symbols for 20 hearing-impaired subjects. The bars represent the standard deviation. The conditions are explained in the text.

In Fig. 4 the difference between SRT in continuous noise and in filtered noise is plotted as a function of the difference between SRT in continuous noise and in interrupted noise, both for the normal-hearing and the hearing-impaired subjects. Only those conditions with comparable (continuous-)noise levels are taken into account (i.e. C85, T85 and F85). When only the energy of the noise is taken into account, a threshold difference for the temporal interruptions of 3 dB (duty cycle 50%) and for the spectral interruptions of 4.7 dB (1/3 octave noise per octave) should be expected.

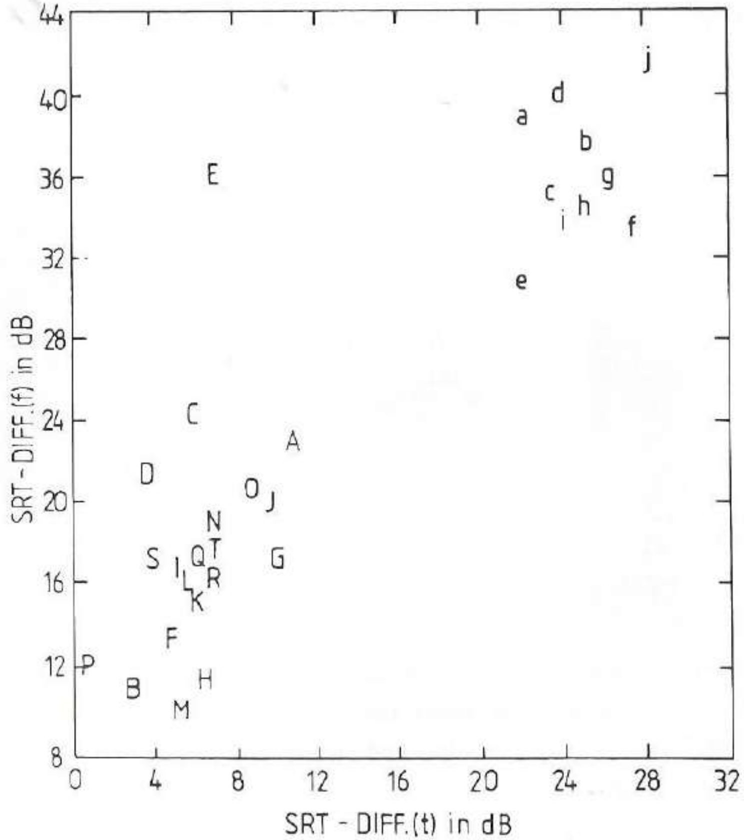


Fig. 4. Difference between SRT in continuous noise and in filtered noise as a function of difference between SRT in continuous noise and in interrupted noise, both for normal-hearing (undercast symbols) and hearing-impaired (uppercast symbols) subjects.

In Fig. 5 the difference between SRT in continuous and in interrupted noise is plotted as a function of the mean hearing level. The SRT results for conditions with comparable (continuous-)noise levels are presented (i.e. the mean result of T75 and T85, and also the mean result of C75 and C85). There is a notable correlation between the two parameters, with a correlation coefficient of 0.85 for the data points of the hearing-impaired subjects.

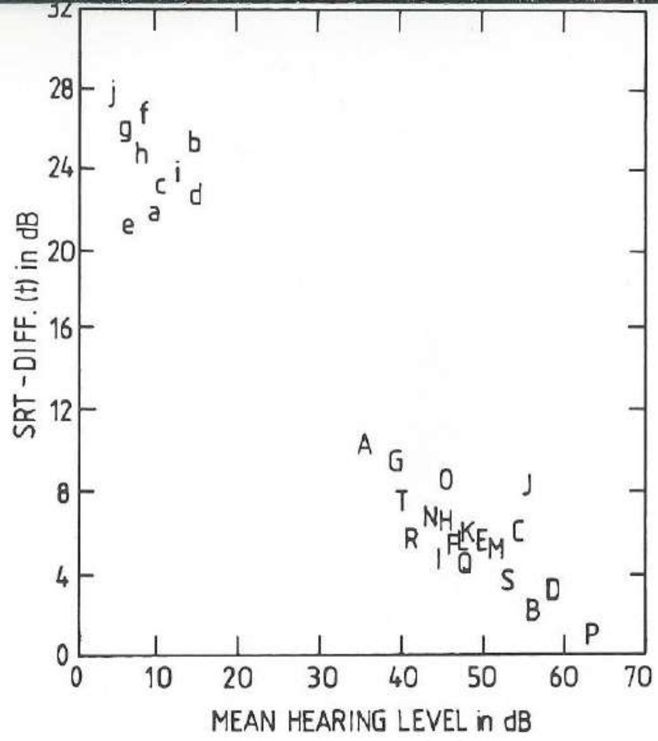


Fig. 5. Difference between SRT in continuous noise and in interrupted noise as a function of mean hearing level, both for normal-hearing (undercast symbols) and hearing-impaired (uppercast symbols) subjects.

In Fig. 6 the logarithms of the values obtained for the auditory-bandwidth experiment are given as a function of the SRT in filtered noise, relative to the mean results for the normal-hearing subjects. The mean results for the conditions F85 and F95 are presented. There is a weak correlation between the two parameters (coefficient 0.49 for the data points of the hearing-impaired subjects) which means that the ear's frequency selectivity is only slightly involved in the SRT measurements with filtered noise.

6.4. DISCUSSION AND CONCLUSIONS

One of the most remarkable results is the fact that the hearing-impaired subjects have a much higher reception threshold for speech in interrupted noise than the normal-hearing subjects.

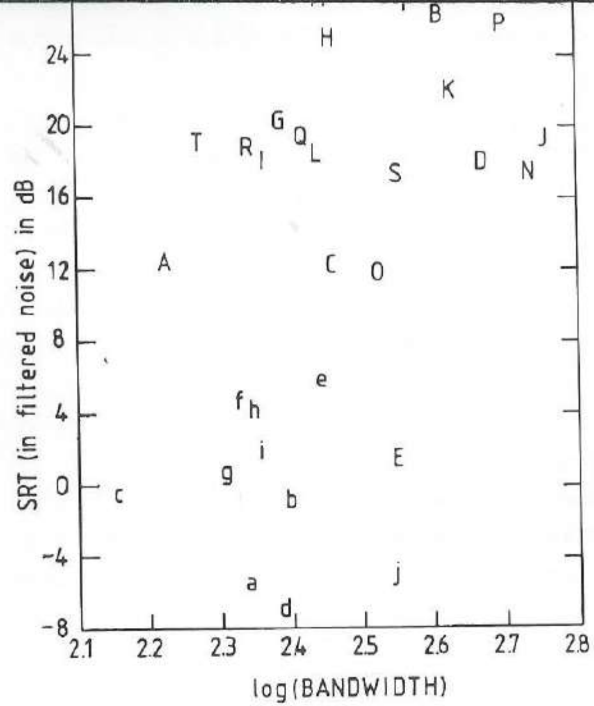


Fig. 6. SRT in filtered noise (relative to the mean results for the normal-hearing subjects) as a function of the logarithm of the auditory bandwidth, both for the normal-hearing (undercast symbols) and hearing-impaired (uppercast symbols) subjects.

This fact can partly be explained by the pure-tone hearing loss of the subjects (correlation coefficient 0.85). We think that hearing loss for speech in interrupted noise is more directly related to the handicap of hearing-impaired people in practical situations than the SRT in continuous noise. With the stimulus configuration described above we reach differences between the hearing-impaired and the normal-hearing subjects up to 30 dB whereas hearing loss for speech in continuous noise only results in differences up to 10 dB (Fig. 2; Plomp, 1986). The differences in hearing loss between hearing-impaired and normal-hearing subjects, found by Festen and Plomp (1986) for speech in sinusoidally intensity-modulated noise, were smaller than the differences for speech in interrupted noise, described above.

Undoubtedly the normal-hearing subjects benefit from the interruptions in the noise far more than the hearing-impaired subjects. As mentioned before, the pure-tone hearing loss of the subjects can only partly explain the higher reception threshold for speech in interrupted noise. Subjects with comparable losses in quiet sometimes show different losses in (interrupted) noise. Apart from the (pure-tone) hearing loss (attenuation), the hearing-impaired listeners are more sensitive to fluctuations in the background noise than the normal-hearing listeners. This sensitivity may be connected to the concentration or the attention of the listeners, thus to more central factors.

Otherwise it should be considered that an increase of 10 dB in noise level causes an increase of 10 dB in SRT in the case of continuous noise and an increase of 7 dB in SRT in the case of interrupted noise for both normal-hearing and hearing-impaired subjects. This last result can partly be explained by the fact that the increase of noise level also affects the unmasked part of the sentences (in the case of interrupted noise): there is a noticeable but decreasing effect of forward masking during the first 200 ms after the noise burst (see e.g. Moore and Glasberg, 1983, and Moore and O'Loughlin, 1986); an increase of 10 dB in noise level causes an increase of about 7 dB in forward-masking level at 50 ms after the noise burst (at that moment the next noise burst starts).

Conclusions of these experiments are:

(1) There is a large difference in hearing loss for speech in interrupted noise between normal-hearing and hearing-impaired subjects. This difference can explain the handicap of hearing-impaired people in practical situations.
(2) Although the reliability of the test is high, the differences between the results of the test and the retest for the conditions in filtered and in interrupted noise spread over a substantially larger range than in continuous noise: about 5 dB for the temporal interruptions and about 3 dB for the spectral interruptions, whereas the SRT levels in continuous noise vary by only about 1 to 2 dB (even when retest and test of one year before are compared).
(3) For almost all subjects the benefit from the discontinuities in the noise is greater than the benefit expected from sound-energy considerations only (for the interrupted-noise and the filtered-noise conditions 3 dB and 4.7 dB respectively).
(4) The mean audiometric loss correlates quite well with the effect of temporal interruptions of the masking noise on SRT.
(5) The auditory bandwidth correlates weakly with SRT in filtered noise.

CHAPTER 7

RELATED AUDITORY MEASURES

Summary

The results of the speech-reception threshold measurements in different noise conditions are compared with differences in pure-tone threshold, auditory bandwidth, temporal resolution, continuity threshold, masking effect of short noise probes by frequency sweeps, and melody-recognition threshold. Close relations are found, for example between results of the sweeping-masker experiment and results of the melody-recognition experiment. Finally, the results of the measurements with fluctuating sound stimuli are reviewed particularly with respect to the explanation of the decreased speech intelligibillity in noise. It appears that the perception or discrimination of fluctuating sound stimuli for hearing-impaired listeners is best when the fluctuations are not fast.

7.1 INTRODUCTION

The complaints of hearing-impaired people are: difficulties in understanding speech in noisy situations, distortion of the sound signal, difficulties in understanding speech in quiet situations, or difficulties in hearing (without details). The complaints can sometimes be explained in terms of attenuation of the signal, distortion of the signal, frequency selectivity, temporal resolution, etc. To describe one of these phenomena many hearing tests are available. Most of the complaints of hearing-impaired people refer to daily situations like listening in a noisy environment (signal-to-noise ratio) or listening to music; therefore, it is difficult to describe these handicaps using tests with stationary signals. For this reason we performed two tests with fluctuating signals: the continuity threshold (Chapter 2) and the masking effect of short noise probes by frequency sweeps (Chapter 3).

Whereas the perception of plosives is vulnerable mostly in noisy situations, one can imagine that plosives are masked by frequency changes or even frequency glides (occurring in the noisy environment). Smoorenburg and Coninx (1980) investigated the masking effect of short probe sounds by tone bursts with a sweeping frequency. We did the same experiments for hearing-impaired listeners (described in Chapter 3). One of the most remarkable results of both studies was that, up to certain sweep speeds, the masked threshold appeared to be higher than the threshold found for stationary maskers.

The results of the experiments mentioned above as well as the results of measurements of various basic auditory functions, such as pure tone threshold at different frequencies, will be compared.

7.2 RESULTS AND DISCUSSION

A group of 20 hearing-impaired and a group of 10 normal-hearing listeners had been subjects in a series of experiments, of which the results can be correlated with each other.

We measured the pure-tone audiogram, the auditory bandwidth, the temporal resolution, the continuity threshold (Chapter 2), the masking effect of short noise probes by frequency sweeps (Chapter 3), the melody-recognition threshold (Chapter 4), the role of co-articulation (Chapter 5), and the speech-reception threshold in different noisy situations (Chapter 6).

For each experiment it was possible to derive about 10 to 15 parameters describing different aspects of the experiment to compare both groups of subjects. In this way we got a list of 87 parameters, from which the parameters presented in Table 1 are the most important ones.

MHL	=	mean hearing loss in dB (0.25, 0.5, 1.0, 2.0, 4.0 kHz)
SLO	=	mean slope in audiogram (0.25, 0.5, 1.0, 2.0, 4.0 kHz)
BAN	=	bandwidth in Hz
WIN	=	window (temporal resolution) in ms
DCP	=	discontinuity perception (percentage)
HXT	=	sweep speed at max. threshold in octaves/second (sweep of 100 ms)
HYT	=	maximum-threshold difference in dB (sweep of 100 ms)
MRT	=	melody-recognition threshold in semitones
SIL	=	speech-reception threshold in silence (in dB)
F85	=	speech-reception threshold in filtered noise of 85 dB
T85	=	speech-reception threshold in pulsating noise bursts of 85 dB
C85	=	speech-reception threshold in continuous noise of 85 dB

Table 1. Parameters used in a series of experiments with hearing-impaired and normal-hearing listeners.

The two parameters of the pure-tone threshold experiment are the mean audiometric loss (MHL, mean hearing loss) and the mean slope (SLO) in the audiogram (Chapter 6, Fig. 1). In the experiments of Dreschler and Plomp (1980) these two parameters appreared to be the most important to describe the audiogram.

Additionally to basic audiometry and SRT measurements the auditory bandwidth (Chapter 6, Fig. 6) and the temporal resolution (Paragraph 2.3.d) of the subjects were measured. These parameters, together with hearing loss, appeared to be the most representative factors with respect to the results of SRT measurements (Festen and Plomp, 1981).

The perception of continuity in interrupted tone stimuli, described in Chapter 2, was investigated in two experiments. In the first experiment, with an adjustment procedure, it was difficult to obtain consistent results. In the second experiment (of Chapter 2), with a two-alternative forced choice procedure, the results were more reliable. One of the parameters derived from this second experiment was the percentage of correct responses on 512 continuous or discontinuous tone stimuli in one trial (Section 2.3.a). The lower this percentage was the higher was the discontinuity-perception level. Two other parameters were the mean sound-pressure level of the tone (tone level) of the continuity-threshold curve and the mean slope in this curve (Chapter 2, Fig. 8). It appeared that the percentage of correct responses and the mean tone level correlated very well with each other (corr. coeff. 0.92) and that the mean slope in the continuity-threshold curve was less important than the mean tone level (less than 15% of variance for the mean slope compared to almost 70% of variance for the mean tone level). So we used the percentage of correct responses as the most representative factor.

Smoorenburg and Coninx (1980) described two parameters in their experiment on masking of short noise probes by frequency sweeps: the sweep speed at which the maximum value of the masked threshold was reached and the level difference between the maximum value and the value of the masked threshold for the stationary masker (Section 3.3). We used these two parameters (for the sweep of 100 ms), scoring more than 65% of the variance, to compare with other results. The correlation of the results for the sweep of 50 ms with the results for the sweep of 100 ms was very high (corr. coeff. 0.96), so it was not necessary to use more than two parameters.

From the melody recognition experiment only one representative parameter was derived which was the recognition threshold of masked melodies in semitones (Chapter 4, Fig. 5).

The results of Chapter 5 in which the perception of plosive consonants was studied were significant for the role of coarticulation: the identification of the consonant influenced by the perception of the transition between vowel and consonant. It was not possible to derive one or two parameters from these experiments which could serve as representative factors for comparing purposes.

The aim of this research project was to describe the perception of fluctuating sounds by hearing-impaired listeners, compared to the perception of stationary sounds at one side and the perception of speech at the other. For this comparison we need some parameters from the experiment described in Chapter 6: the reception threshold of interrupted speech. SRT measurements often result in a factor which represents the hearing loss for speech in quiet, and a factor which represents the hearing loss for speech in noise (Plomp, 1978). The last factor is mainly the effect of distortion of the stimulus, and the first factor is mainly the effect of attenuation of the stimulus, only partly the effect of distortion of the stimulus. In our experiments we used continuous masking noise but also filtered noise and pulsating noise bursts. From all test conditions we extracted four representative parameters: the hearing loss for speech in quiet (SRT in silence), and the hearing loss for speech in continuous noise, filtered noise and pulsating noise bursts, respectively. The parameters were choosen for the conditions with noise levels of 85 dB, not for lower levels, to avoid influence of the hearing threshold.

Table 2 contains the correlation matrix for the 12 parameters selected in Table 1. To investigate the influence of the hearing threshold upon the relations mentioned in Table 2, also the correlation matrix for the 12 parameters selected in Table 1 has been calculated with the mean hearing loss (MHL) partialled out, see Table 3.

Comparing the results of Table 2 with the results of Table 3 we see that the auditory bandwidth correlates with the temporal window (BAN and WIN, corr. coeff. 0.64), but with the mean hearing loss partialled out this correlation drops to a lower level (corr. coeff. 0.44).

For parameters derived from the speech-reception threshold experiments (Chapter 6) and parameters derived from the bandwidth measurements (Chapter 6) we found low correlation coefficients e.g. 0.49 for the SRT in filtered noise as a function of the auditory bandwidth relative to the mean results for the normal-hearing subjects (Chapter 6, Fig. 5).

MHL											
.07	SLO										
.70	.08	BAN									
.53	-.17	.64	WIN								
-.01	.21	-.26	-.38	DCP							
.41	-.03	.24	.04	.05	HXT						
.15	-.65	.19	.23	-.09	.21	HYT					
-.11	-.55	-.17	.14	-.15	-.12	.67	MRT				
.46	-.51	.19	.01	.07	.61	.62	.23	SIL			
.17	-.19	.09	-.12	.15	.51	.28	.08	.65	F85		
.64	.23	.49	.06	.19	.28	.21	.01	.48	.39	T85	
.43	.15	.50	.36	.13	-.06	.29	.21	.21	.25	.75	C85

Table 2. Correlation coefficients between different parameters derived from a battery of experiments with hearing-impaired subjects (the level of significance for corr.coeff.>0.59 is P<0.01).

MHL											
.00	SLO										
.00	.05	BAN									
.00	-.24	.44	WIN								
.00	.21	-.35	-.44	DCP							
.00	-.06	-.07	-.24	.06	HXT						
.00	-.67	.12	.18	-.08	.16	HYT					
.00	-.55	-.13	.23	-.15	-.08	.69	MRT				
.00	-.61	-.22	-.31	.08	.52	.63	.33	SIL			
.00	-.20	-.09	-.25	.16	.49	.26	.10	.65	F85		
.00	.24	.08	-.42	.26	.03	.15	.11	.27	.37	T85	
.00	.13	.30	.17	.15	-.29	.26	.29	.02	.20	.69	C85

Table 3. Correlation coefficients between different parameters derived from a battery of experiments with hearing-impaired subjects with the mean hearing loss (MHL) partialled out (the level of significance for corr.coeff.>0.59 is P<0.01).

For parameters derived from the experiment with the sweeping masker (Chapter 3) and parameters derived from the melody-recognition experiment (Chapter 4) we found high correlation coefficients (e.g. 0.67, $P<0.01$) for the melody-recognition threshold (in semitones) with the maximum-threshold difference (sweep of 100 ms), for the hearing-impaired subjects (MRT with HYT in Table 2, Fig. 1). We see that the masked threshold of the tone bursts with sweeping frequency is high for subjects who have a high melody-recognition threshold. The results for the normal-hearing subjects showed that a low melody-recognition threshold is related to a low maximum threshold difference. When people mention the disturbing effect of melodies which mask the melody to be detected, it can be expected that a tone burst with a sweeping frequency has a great masking effect upon a short probe stimulus. In Figure 1 we see that the results for the normal-hearing subjects show the same tendency: the masked threshold is higher for subjects who have a higher melody-recognition threshold (corr. coeff. 0.53).

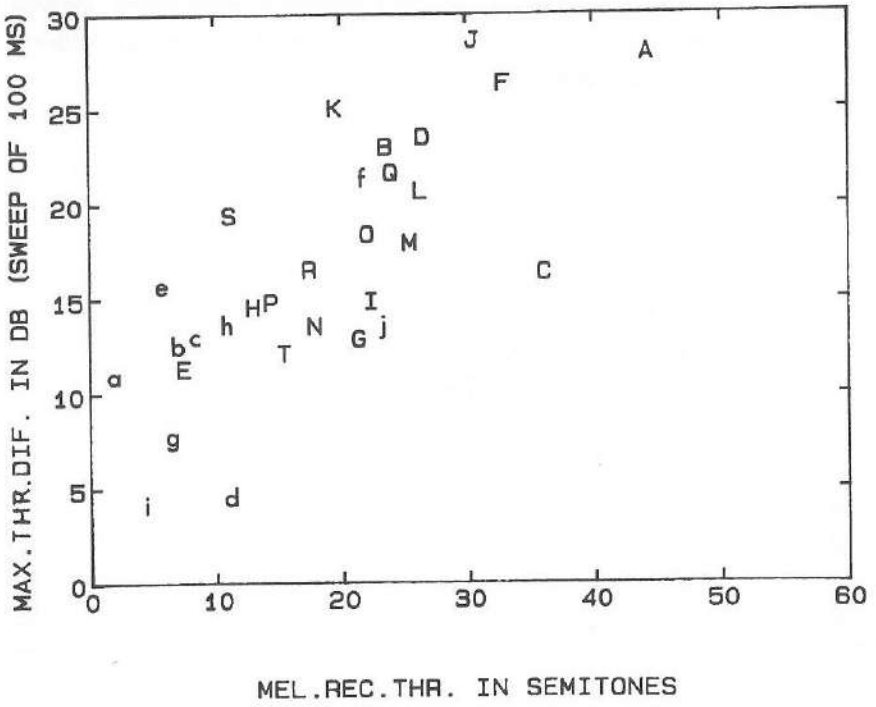


Fig. 1. Maximum-threshold difference for a sweep of 100 ms and melody-recognition threshold for 20 hearing-impaired subjects (individually indicated by uppercast symbols), and for 10 normal-hearing subjects (undercast symbols).

The relation between the parameters HYT and MRT (Figure 1) is maintained when the mean hearing loss is partialled out (corr. coeff. 0.67 in Table 2 and 0.69 in Table 3).

Another remarkable relation can be found between the parameters SLO and HYT (corr. coeff. -0.54 in Table 2 and -0.67 in Table 3). In this case the slope in the audiogram correlates in negative sense with the maximum-threshold difference in the sweeping-masker experiment (sweep of 100 ms). This means that a steep audiogram gives a condition in which the target in the sweeping-masker experiment is better detected when the masker is swept (less contribution in masking from the high frequency part of the masker).

Generally, we may conclude from the experiments, described before and the correlations mentioned above, that the pure-tone audiogram represents the fundamental measure for hearing impairment (resulting from principal-component analysis upon the sampled data). Apart from the attenuation factor which is the main part of the impairment for most hearing-impaired subjects, also distortion aspects, the temporal and spectral infuences, and more central factors of the auditory pathway play an important role in the description of the practical disabilities of impaired listeners. The next items correspond to those extra measures and related factors.

The auditory bandwidth of the subjects is large in cases of pronounced hearing losses (BAN and MHL in Table 2). Looking to the correlation coefficient between the results of the bandwidth experiment and the results of the speech-reception threshold measurements (for example BAN and C85 in Table 2) the reduced speech intelligibility in different (interrupted) noise conditions can partly be explained by the less sensitive frequency selectivity of the peripheral ear.

The temporal resolution is a factor which is related to the fundamental measures extracted from basic audiometry (pure-tone hearing loss and auditory bandwidth, MHL and BAN in Table 2) but also to some other measures (e.g. derived from the sweeping-masker experiment, described before in this chapter).

The continuity threshold has hardly any relations with other functions measured (when not influenced by the increased pure-tone threshold of the impaired ear). It describes the sensitivity of the subjects to extract the target signal from the noisy background, without hindrance of the interruptions in the noise. The continuity threshold drops to lower tone-burst levels for larger tone-noise periods (Chapter 2, Fig. 8). This could mean that when listening to a fluctuating stimulus (like speech), the perception or discrimination of that stimulus is best when the fluctuations are not fast.

This point can also be concluded from the result of the experiments in Chapter 3 with the sweeping masker. The masking reaches its maximum at a lower sweep speed for hearing-impaired listeners than for normal-hearing listeners (Chapter 3, Fig. 4). Again for the hearing-impaired listeners the difficulties are greater when the fluctuations are fast.

The sweeping-masker threshold has some close connections to other measures, as to the melody-recognition threshold (described before in this chapter, Fig. 1), when the subjects have to detect targets in the auditory field, masked by signals fluctuating (sometimes very quickly) in time and/or varying in frequency. For both measures the central factor of the hearing impairment (like discrimination) plays an important role. As mentioned before, the melody-recognition threshold is much higher for hearing-impaired listeners than for normal-hearing listeners (Chapter 4, Fig. 6). However, there is no correlation with the subjects' auditory bandwidth (Chapter 4, Fig. 7).

The results of the experiments in which the role of co-articulation (in perceived speech signals) was investigated (Chapter 5), show that the VC and CV transitions in the perception of consonants are more important for hearing-impaired listeners than for normal-hearing listeners (Chapter 5, Tables 6 & 7, identification with the plosive bursts only results in guessing for the hearing-impaired subjects). This, again, means that fast transitions between consonants and vowels have a negative influence on the percepti-on of the consonants. The results combine the factors which describe the perception of targets masked by signals fluctuating in time and/or varying in frequency and the factors which describe the perception of targets (like consonant-vowel transitions) which are fluctuating in time and/or varying in frequency themselves.

The latter factors are in close connection with the results of the SRT measurements in different (noisy) situations (Chapter 6). In those measurements the sound-pressure level of the speech stimulus, interrupted by noise bursts, must be much higher for the hearing-impaired listeners to understand the speech than for the normal-hearing listeners (Chapter 6, Fig. 3).

In the previous chapters we described experiments on the perception of fluctuating sound stimuli by hearing-impaired listeners. We found many results, that told us something about the way in which hearing-impaired

people have difficulties in different listening situations. Auditory functions, measured with stationary sound stimuli, explain the greater part of the hearing handicap. We tried to find the missing part, especially the explanation of the decreased speech intelligibillity in noise, with functions based on fluctuating sound stimuli. We found some remarkable results: close relations between results of the sweeping-masker experiment and the melody-recognition threshold, the important role of VC and CV transitions in the perception of plosive consonants, the larger range of the transition between the perception of continuity and discontinuity for hearing-impaired subjects and the repeated finding that the impaired ear is more sensitive to fluctuations, especially when the fluctuations are fast.

SUMMARY

Many hearing-impaired subjects have difficulties in understanding speech in situations with interfering sounds (e.g. competing talkers, traffic noise, music). In previous dissertations from our laboratory, Festen (1983) and Dreschler (1983) have tried to explain these difficulties on the basis of deteriorated primary auditory functions like frequency resolution and temporal resolution. Their findings showed that these auditory functions can be responsible for only part of the speech-perception problems by the hearing impaired.

A possible explanation for this result may be that the primary auditory functions studied were too remote from the parameters involved in speech understanding to be fully succesful. The rapidly fluctuating speech signal seems to ask for a comparison with more complex stimuli to get a better insight into the underlying factors of deteriorated speech perception. This holds the more in view of the finding that a single competing voice (Duquesnoy, 1983), or a rapidly varying noise (Festen and Plomp, 1986b), interferes much stronger with speech intelligibility of hearing-impaired subjects than steady-state noise. Apparently, it is worthwhile to supplement the previous studies with new experiments in which sound stimuli with widely divergent sorts of spectro-temporal fluctuations are involved.

The present study presents the results of a series of experiments selected to meet this demand. In each of them the perception of particular complex sounds by hearing-impaired subjects is investigated. In order to reduce the number of disturbing factors as much as possible, the same group of 20 test subjects was used in most experiments. This has the important advantage that interrelations of the data from the various tests can be studied by means of correlation techniques.

Chapter 2 reports experiments in which the continuity threshold of normal-hearing and hearing-impaired listeners was measured for bursts of pure tones alternated with noise bursts (equal duration of tone and noise bursts). In the first experiment the tone bursts included three types: constant frequency, modulated in frequency, increasing frequency. For the normal-hearing subjects the sound-pressure level at the continuity threshold is lower for large tone-noise periods than for short periods. For the hearing-impaired subjects it was difficult to obtain consistent results. Therefore, we carried out another experiment, in which the tone-noise period varied from 100 ms to 800 ms and the tone level varied over a

range of 40 dB around most comfortable level. A special measuring technique (tone stimuli superimposed on or interrupted by a single noise burst) made it possible to obtain highly consistent and reliable results. For the normal-hearing as well as for the hearing-impaired subjects the continuity threshold drops to lower tone-burst levels for larger tone-noise periods. The range of the transition between the perception of continuity and discontinuity is larger for the hearing-impaired than for the normal-hearing listeners due to more variability and to a greater effect of hysteresis.

Smoorenburg and Coninx (1980) investigated the masking of short narrow-band noise bursts with a constant frequency by longer tone bursts with a sweeping frequency. One of the most remarkable results of their study was that, up to certain sweep speeds, the masked threshold appeared to be higher than the threshold found for stationary maskers. This is in contradiction with current masking theories based on detection of energy increments in critical bands. The aim of the experiment, described in **Chapter 3**, was to investigate whether this behaviour found for normal-hearing listeners can also be observed for hearing-impaired listeners. Those subjects have problems in understanding speech, being a fluctuating sound, especially against a background of noise. This might suggest that for those subjects short probe sounds can be masked even more easily. The results show that for the hearing-impaired subjects the masked threshold was maximal at a sweep speed of 25 oct/sec and on the average 21 dB higher than for stationary maskers (0 oct/sec). This sweep speed is lower, and the threshold elevation is higher than for normal-hearing listeners.

Chapter 4 introduces the recognition threshold of a short melody presented simultaneously with two other melodies, lower and higher in frequency, respectively. The threshold was defined as the frequency distance required to recognize the test melody. It was found that, whereas the mean recognition threshold for the normal-hearing subjects was five semitones, it was, on the average, 27 semitones for the hearing-impaired subjects. Although the interindividual spread for the latter group was large, the recognition threshold dit not correlate with auditory bandwidth, nor with musical experience or education.

In **Chapter 5** the role of co-articulation is studied. From 45 embedded CVCVC words we deleted either the plosive bursts, or the vocalic CV or VC transitions, or the stationary vowel portions, or any combination of these four. The listeners were asked to identify the three plosive consonants in the resulting stimuli. The results for the normal-hearing

subjects agree with results of Schouten and Pols (1983): Identification is affected more by deletion of plosive bursts than of vocalic transitions, and in medial consonants the CV transition contains more information about the consonant than the VC transition does. For the hearing-impaired listeners the vocalic transitions play a more important role: identification with the plosive bursts only results in guessing. In contrast with the results for the normal-hearing subjects, more errors occur for the final consonant than for the initial or the medial consonant.

In the experiments, descibed in **Chapter 6**, in which the speech-reception threshold (SRT) was measured, we used noise, interrupted in time or filtered in frequency, comparable to daily-life situations. It appeared that normal-hearing listeners benefit more from the silent intervals between the noise bursts to understand speech than hearing-impaired listeners. The average SRT difference between normal-hearing and hearing-impaired listeners measured in interrupted noise was 15-20 dB, whereas the average SRT difference in continuous noise was only about 3 dB.

In the concluding **Chapter 7** the results of the speech-reception threshold measurements in different noise conditions are compared with differences in pure-tone threshold, auditory bandwidth, temporal resolution, continuity threshold, masking effect of short noise probes by frequency sweeps, and melody-recognition threshold. In the last three cases fluctuating tone stimuli were involved. Although some significant correlations were found, the predictive value of these experiments appeared to be much lower than of the experiments with stationary tone stimuli.

We may conclude that the experiments described in this thesis have contributed to our knowledge of the perception of fluctuating stimuli by hearing-impaired subjects. The original question underlying this research whether the difficulties of the hearing impaired in understanding speech in noise is related to difficulties in the perception of fluctuating tone stimuli cannot be answered positively. In this respect, experimental data obtained with stationary stimuli seem to be more important than data obtained with the fluctuating stimuli used in this study.

SAMENVATTING

Veel slechthorenden ondervinden problemen in het verstaan van spraak, in het bijzonder als spraak door andere geluiden verstoord wordt (zoals geroezemoes, verkeerslawaai, muziek). In vorige dissertaties die in ons laboratorium tot stand gekomen zijn, hebben Festen (1983) en Dreschler (1983) geprobeerd deze problemen te verklaren door het niet goed functioneren van de primaire auditieve functies zoals frequentie- en tijdoplossend vermogen. Hun bevindingen toonden aan dat deze auditieve functies slechts ten dele verantwoordelijk kunnen zijn voor de problemen in het verstaan van spraak.

Een mogelijke verklaring voor dit resultaat kan zijn dat de bestudeerde primaire auditieve functies niet op één lijn stonden met de parameters die het verstaan van spraak beschrijven. Het snel variërende spraaksignaal vereist schijnbaar een vergelijking met ingewikkelder stimuli om beter inzicht te krijgen in de factoren die ten grondslag liggen aan de verminderde spraakverstaanvaardigheid. Dit stemt overeen met het resultaat dat één spreker als stoorbron (Duquesnoy, 1983), of snel variërende maskeergeluiden (Festen en Plomp, 1986b) veel meer raakvlakken hebben met de spraakverstaanvaardigheid van slechthorenden dan stationaire ruis. Blijkbaar is het de moeite waard de vorige studies aan te vullen met nieuwe experimenten waarin geluidstimuli voorkomen die een breed scala van spectro-temporele fluctuaties bevatten.

In deze studie worden experimenten uitgevoerd die aan deze voorwaarden voldoen. In elk experiment is onderzocht hoe slechthorenden bijzondere complexe geluidstimuli waarnemen. Om onderlinge vergelijking mogelijk te maken werden de meeste experimenten uitgevoerd met steeds dezelfde groep van 20 slechthorenden. Dit heeft het belangrijke voordeel dat onderlinge relaties tussen de resultaten van de verschillende experimenten bestudeerd kunnen worden door middel van correlatie-technieken.

Hoofdstuk 2 rapporteert experimenten waarin de continuiteitsdrempel van normaal- en slechthorenden gemeten werd voor toonstootjes die afgewisseld werden door ruisstootjes (gelijke duur van toon- en ruisstootje). In het eerste experiment werden drie soorten toonstootjes gebruikt: constante frequentie, gemoduleerd in de frequentie en met stijgende frequentie. Voor de normaalhorenden is het geluiddrukniveau van de continuiteitsdrempel lager voor lange toon-ruisperioden dan voor korte perioden. Voor de slechthorenden was het moeilijk consistente resultaten te verkrijgen. Daarom werd een ander experiment uitgevoerd waarin de toon-ruisperiode variëerde van 100 tot 800 milliseconde en het geluiddrukniveau van het toonstootje over een bereik van 40 dB rond het meest aangename geluiddrukniveau. Een speciale meet-techniek (toonstootjes al dan niet onderbroken door ruisstootjes) maakte het mogelijk consistente en betrouwbare resultaten te verkrijgen. Zowel voor de normaalhorenden als voor de slechthorenden daalt de continuiteitsdrempel naar lagere geluiddrukniveaus van het toonstootje als de toon-ruisperiode langer wordt. Het overgangsgebied van de waarneming van continuiteit naar discontinuiteit is groter voor de slechthorenden dan voor de normaalhorenden vanwege de grotere variabiliteit en de grotere hysterese.

Smoorenburg en Coninx (1980) onderzochten het maskeren van korte smalbandige ruisstootjes van constante frequentie door langere toonstootjes met stijgende of dalende frequentie. Eén van de opmerkelijkste resultaten van hun onderzoek was dat, tot bepaalde stijg- of daalsnelheden, de maskeerdrempel hoger bleek te liggen dan de drempel die gevonden werd met stationaire maskeergeluidjes. Dit is in tegenspraak met de huidige theorieën over maskering die gebaseerd zijn op energiedetectie in kritische frequentiebanden. Het doel van het experiment, beschreven in **Hoofdstuk 3**, was na te gaan of dit verschijnsel dat bij normaalhorenden optrad ook opgaat voor slechthorenden. Deze categorie ondervindt problemen in het verstaan van spraak, dat een fluctuerend geluidsignaal is, in het bijzonder tegen een achtergrond van ruis. Dit zou kunnen betekenen dat voor deze categorie korte geluidsignalen in versterkte mate gemaskeerd kunnen worden. De resultaten voor de slechthorenden laten zien dat de maskeerdrempel maximaal is bij een stijgsnelheid van 25 octaven/seconde en gemiddeld 21 dB hoger ligt dan de drempel met stationaire maskeergeluidjes (0 octaven/seconde). De eerste waarde ligt lager, de tweede waarde ligt hoger dan de waarden die voor normaalhorenden gevonden werden.

Hoofdstuk 4 introduceert de herkenningsdrempel van een korte melodie die gelijktijdig ten gehore gebracht wordt met twee andere melodietjes, die lager en hoger van frequentie zijn. De drempel werd gedefiniëerd als de kleinste frequentie-afstand tussen de melodietjes, waarbij de testmelodie nog net herkend kan worden. De gemiddelde herkenningsdrempel bleek voor de normaalhorenden vijf halve tonen te bedragen, en voor de slechthorenden 27 halve tonen. Hoewel de interindividuele spreiding voor de laatste groep groot was, correleerde de uitkomst niet met de auditieve bandbreedte, noch met hun muzikale ervaring of opleiding.

In **Hoofdstuk 5** wordt de rol van coarticulatie bestudeerd. Van 45 in korte zinnetjes opgenomen CVCVC-woorden verwijderden we het plofgedeelte van de medeklinker, of de overgang van medeklinker naar klinker, of het stationaire gedeelte van de klinker, of een combinatie hiervan. De luisteraars werden gevraagd de drie plofklanken in de resulterende stimulus te identificeren. De resultaten voor de normaalhorenden komen overeen met de resultaten van Schouten en Pols (1983): de identificatie is moeilijker als het plofgedeelte van de medeklinker weggelaten wordt dan bij het verwijderen van de CV- of VC-overgang. Bij de middenmedeklinkers bevat de CV-overgang meer informatie over de medeklinker dan de VC-overgang. Voor de slechthorenden speelt de CV- of VC-overgang een nog belangrijkere rol: de identificatie onderscheidt zich niet van gissen als alleen de plofklank ten gehore gebracht wordt. In tegenstelling tot de resultaten bij de normaalhorenden, treden er meer fouten op voor de eindmedeklinker dan voor de begin- of middenmedeklinker.

In de experimenten, beschreven in **Hoofdstuk 6**, waarin de spraakverstaanvaardigheidsdrempel (SRT) werd gemeten, gebruikten we ruis als stoorsignaal, in de tijd onderbroken of in de frequentie gefilterd, vergelijkbaar met dagelijkse situaties. Het bleek dat normaalhorenden meer voordeel hadden van de stille intervallen tussen de ruisstootjes om de spraak te verstaan dan slechthorenden. Het gemiddelde verschil in SRT tussen normaalhorenden en slechthorenden bij temporeel onderbroken ruis bedroeg 15-20 dB, terwijl het verschil bij continue ruis slechts ongeveer 3 dB was.

In het afsluitende **Hoofdstuk 7** worden de resultaten van de spraakverstaanvaardigheids-metingen in verschillende ruis-omstandigheden vergeleken met de verschillen in toondrempel, auditieve bandbreedte, temporele resolutie, continuinuiteitsdrempel, het maskeren van korte ruisstootjes door toonstootjes met stijgende frequentie, en melodieherkenningsdrempel. In de laatste drie gevallen werden variërende geluidstimuli gebruikt. Hoewel enige significante correlaties gevonden werden bleek de voorspellende waarde van deze experimenten veel lager te zijn dan van de experimenten met stationaire geluidstimuli.

We kunnen concluderen dat de experimenten die in dit proefschrift beschreven zijn bijdragen aan onze kennis van de perceptie van variërende geluidstimuli door slechthorenden. De oorspronkelijke vraag, die aan dit onderzoek ten grondslag ligt, namelijk of de moeilijkheden die slechthorenden ondervinden bij het verstaan van spraak in ruis gerelateerd is aan moeilijkheden in de perceptie van variërende geluidstimuli, kan niet positief beantwoord worden. In dit opzicht lijken de resultaten die verkregen zijn met stationaire geluidstimuli van meer belang te zijn dan de resultaten die verkregen zijn met variërende geluidstimuli, die in dit onderzoek gebruikt zijn.

APPENDICES

The next 12 appendices contain the results of 10 normal-hearing and hearing-impaired subjects for all experiments, described before. The normal-hearing subjects are indicated by lower-case symbols, the hearing-impaired subjects by upper-case symbols. All numbers represent the average results of test and retest.

App. 1 Mean results of all subjects for almost all measurements. The indicators of the columns correspond to parameters, described in Table 1 of Chapter 7.

App. 2 Results for pure-tone audiometry for 19 different frequencies (columns), at 1/3-octave intervals (Fig. 2 in Chapter 3).

App. 3 Results for the auditory-bandwidth experiment. The detection thresholds at the peak (P) and in the valley (V) of the noise signal, with ripple densities of 1/2, 1, and 2 ripples per 1000 Hz, and the differences (D) are given (Fig. 6 in Chapter 6).

App. 4 Results for the temporal-resolution experiment. The detection thresholds at the peak (P) and in the valley (V) of the noise signal, with intensity-modulation frequencies of 5, 10, and 15 Hz, and the differences (D) are denoted (Paragraph 3d in Chapter 2).

App. 5 Continuity thresholds (in dB) for eight different tone-noise periods (steps of 100 ms) and eight different levels of the 1000-Hz tone (steps of 10 dB, Fig. 8 in Chapter 2).

App. 6 Masked thresholds of short noise probes in the frequency-sweep experiment, relative to the masker level (in dB). The masker duration was 100 ms (H) or 50 ms (F), the sweep speed varied between 0 and 60 (H) or 120 (F) oct/sec (Fig. 4 in Chapter 3).

App. 7 Speech-reception thresholds in 10 listening conditions: in quiet (SIL), in filtered noise (F), in noise interrupted in time (T), and in continuous noise (C); the numbers in the columns indicate the continuous noise level (Fig. 3 in Chapter 6).

App. 8 Percentages of correct responses for initial unvoiced consonants for the 13 stimulus conditions (described in Figure 1 of Chapter 5) in the co-articulation experiment (also Table 3 in Chapter 5).

App. 9 Same as App. 8 but now for initial voiced consonants.

App. 10 Same as App. 8 but now for medial unvoiced consonants.

App. 11 Same as App. 8 but now for medial voiced consonants.

App. 12 Same as App. 8 but now for final unvoiced consonants.

Appendix 1. Mean results of all subjects for almost all measurements.

	MHL	SLO	BAN	WIN	MRT	DCP	HXT	HYT	FXT	FYT	SIL	F85	T85	C85	FDM	TDM	CDM	CFM	CTM
a	9.54	4.44	213.45	41.46	3.22	55.47	16.51	11.06	39.77	16.77	20.40	38.80	55.20	79.80	8.30	5.80	10.20	39.20	22.20
b	12.80	1.20	244.38	56.15	8.07	49.35	25.23	12.37	34.73	14.20	16.20	43.60	52.40	80.80	11.90	5.20	10.50	38.10	25.10
c	10.34	2.51	140.66	32.67	8.65	57.68	20.76	12.41	38.53	15.32	19.00	44.00	53.80	80.20	8.90	6.90	10.00	35.30	23.40
d	13.86	1.01	253.84	38.85	11.60	57.55	8.95	3.25	19.36	9.49	16.40	37.00	55.80	80.00	10.80	6.60	9.70	39.70	23.10
e	6.86	0.14	290.62	31.11	6.95	32.29	42.29	16.24	63.16	16.02	14.00	51.00	57.80	80.80	12.10	8.40	9.50	31.20	22.40
f	8.20	0.30	203.29	28.22	22.52	59.37	45.61	21.67	157.36	28.34	10.40	50.20	54.00	81.20	15.80	7.10	10.50	33.10	26.80
g	7.66	2.51	202.20	36.01	7.97	34.77	13.43	9.20	24.57	12.53	13.60	45.60	51.00	80.40	11.70	6.40	9.80	36.40	25.80
h	8.30	2.14	212.29	32.32	10.25	45.18	26.65	14.43	154.90	30.19	19.80	50.00	56.60	81.60	14.30	6.00	10.90	34.60	25.10
i	11.50	2.02	214.60	44.72	2.97	28.25	22.04	4.84	66.94	12.18	13.80	46.40	52.60	80.00	13.00	6.30	10.30	35.50	24.20
j	4.38	-0.27	353.17	54.94	21.75	32.55	23.47	12.89	61.73	16.59	11.00	38.40	50.40	81.80	11.60	4.10	10.50	41.70	27.90
A	33.14	0.25	164.59	18.50	44.28	41.67	18.13	27.88	31.13	27.09	51.00	57.40	71.60	82.20	3.20	5.80	10.10	22.30	10.00
B	57.16	8.99	393.57	32.32	23.58	43.75	28.03	22.97	28.89	18.54	59.80	71.80	78.60	81.60	5.60	6.80	8.00	9.90	3.10
C	56.60	12.73	327.39	41.91	36.08	47.53	15.42	16.27	25.23	15.45	43.20	56.00	77.40	85.20	7.90	8.80	11.40	23.80	6.20
D	58.80	12.28	468.04	31.28	26.48	53.78	20.47	23.45	28.61	25.38	55.20	62.40	81.00	87.40	6.90	8.20	10.00	21.30	3.80
E	50.52	21.03	391.47	31.63	7.45	53.39	20.14	11.27	41.98	10.65	33.40	44.80	76.40	83.60	6.60	8.40	8.30	37.10	6.20
F	47.16	10.28	370.84	18.01	32.92	67.06	21.26	26.30	31.39	22.32	55.60	74.00	86.00	90.60	7.30	10.10	11.10	13.10	4.60
G	39.08	18.56	247.04	28.07	21.38	49.35	19.87	12.78	21.19	11.31	34.60	64.20	70.40	82.40	7.40	4.30	10.00	16.90	9.80
H	47.52	8.18	287.49	27.18	13.00	53.12	21.77	14.52	30.99	24.13	47.40	69.60	72.80	82.60	8.70	6.40	8.70	11.20	6.40
I	44.60	11.83	241.75	18.40	22.35	42.06	27.30	14.81	46.55	15.30	49.60	62.20	75.80	81.00	3.90	6.10	8.10	17.10	5.20
J	57.66	1.92	544.67	82.92	30.55	42.97	24.52	28.57	30.51	28.70	53.00	63.20	76.00	87.00	3.10	7.40	11.10	19.70	9.40
K	48.18	7.50	424.57	23.23	19.60	43.10	29.55	25.00	23.07	22.18	57.20	66.20	74.00	82.80	5.80	5.30	9.70	14.40	6.40
L	47.72	10.58	272.33	27.77	26.27	72.53	30.38	20.59	30.99	17.29	53.00	62.40	72.80	81.80	4.50	5.70	9.20	16.00	6.10
M	49.96	6.60	272.33	15.64	25.40	66.02	31.18	17.83	34.31	14.07	55.80	70.80	77.00	82.00	5.20	6.90	9.60	9.80	4.80
N	42.46	16.48	527.26	34.86	17.88	41.41	20.04	13.49	29.38	12.37	37.20	60.80	74.80	83.60	5.60	8.70	9.90	18.90	6.90
O	45.10	-1.57	330.95	29.64	22.05	45.57	14.98	18.28	24.56	28.49	49.40	56.80	70.40	80.40	5.50	6.60	10.20	20.90	8.60
P	62.08	13.42	499.46	42.37	14.43	42.71	31.09	14.76	69.82	12.90	62.40	70.20	83.60	87.20	0.90	5.30	8.00	11.60	0.30
Q	45.88	11.05	257.98	29.96	23.90	44.27	24.45	21.54	32.59	19.15	52.80	64.60	74.40	83.40	7.60	5.80	10.50	17.30	5.80
R	39.92	11.48	234.02	19.85	17.48	44.79	18.80	16.47	14.66	13.02	46.60	63.80	75.00	82.80	10.20	7.20	10.00	16.30	6.30
S	52.06	14.26	362.89	17.06	11.07	70.05	23.27	19.37	25.43	18.78	53.60	62.40	79.20	82.60	5.00	8.60	8.90	17.00	3.90
T	39.64	14.21	188.44	20.07	15.43	70.44	15.50	12.06	16.84	20.93	45.60	63.40	73.40	84.20	7.40	7.90	10.00	16.90	7.70

Appendix 2. Results for pure-tone audiometry for 19 different frequencies.

	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
a	6.10	1.60	3.20	-3.30	4.20	-3.20	5.80	14.30	11.70	18.20	14.60	17.30	10.40	18.30	19.00	16.60	17.30	15.10	17.10
b	14.00	12.00	7.90	8.00	11.10	11.60	12.20	11.90	14.40	16.90	16.40	16.30	13.60	16.70	14.70	13.30	13.60	11.00	15.50
c	11.40	7.30	8.70	5.50	7.20	9.30	8.50	13.20	13.60	6.90	17.70	18.60	17.00	17.40	19.90	13.80	20.50	19.30	9.90
d	15.50	13.00	9.90	11.20	12.10	13.00	14.10	16.20	13.30	9.90	17.90	19.60	21.60	13.40	13.90	12.50	19.90	16.40	17.90
e	10.90	7.60	6.60	6.20	3.80	2.70	6.50	5.60	9.10	7.50	7.70	9.90	7.90	8.00	7.50	6.20	11.40	12.60	2.00
f	9.80	4.50	7.70	5.80	8.70	6.90	9.20	10.90	9.70	8.30	10.80	11.00	11.60	12.10	7.90	6.10	7.90	11.80	10.50
g	13.10	6.90	5.60	5.10	4.70	5.60	4.70	7.20	8.80	3.90	5.80	7.70	9.20	13.20	16.10	15.40	11.20	21.30	12.00
h	4.60	1.30	5.90	5.50	5.80	7.80	6.70	7.80	10.70	3.00	5.40	8.00	13.50	13.50	12.20	12.80	8.10	27.00	20.80
i	8.40	4.80	7.30	9.00	7.40	7.50	8.60	9.90	12.50	11.00	11.60	14.30	11.00	8.00	12.10	17.90	16.20	8.80	12.20
j	4.40	5.40	3.70	4.60	4.40	3.30	6.10	6.30	8.30	4.40	4.70	4.10	1.00	4.30	12.20	5.80	2.50	1.60	-0.40
A	33.50	32.00	33.50	34.50	31.80	34.40	33.90	32.20	33.40	33.00	35.30	30.80	23.20	32.30	29.10	41.10	38.60	60.20	67.10
B	22.00	24.40	26.90	35.60	41.80	49.80	51.60	51.40	54.20	61.00	67.60	69.50	62.50	63.50	67.60	75.10	79.80	80.00	72.40
C	27.60	27.00	28.70	31.10	33.40	42.80	46.20	47.20	51.70	50.00	66.10	66.10	75.70	76.80	79.20	80.00	77.70	76.60	78.10
D	32.80	30.70	31.80	33.10	40.70	40.90	46.90	53.30	58.30	58.10	61.10	68.10	75.90	76.80	79.90	80.00	80.00	80.00	80.00
E	7.60	2.90	3.90	6.20	4.90	10.70	16.10	38.20	61.50	71.50	75.50	77.50	78.80	79.60	79.00	80.00	79.70	80.00	71.40
F	24.30	27.10	27.60	32.40	39.40	40.70	41.50	36.10	32.20	32.80	49.20	44.50	49.10	57.30	66.90	80.00	80.00	80.00	77.50
G	18.90	13.30	14.30	6.60	12.20	11.60	12.70	14.40	21.80	37.70	59.30	65.90	65.30	65.90	63.80	73.10	79.30	78.20	71.70
H	55.20	49.70	46.30	45.20	40.90	37.00	34.10	27.40	23.00	29.70	50.20	47.60	50.90	58.80	63.80	77.70	80.00	80.00	80.00
I	17.70	15.70	18.00	23.10	24.10	26.60	28.90	32.90	40.50	44.40	53.40	57.80	59.80	58.50	57.80	66.80	72.90	67.30	57.70
J	49.00	49.50	54.80	53.80	56.40	61.30	59.90	60.80	64.90	54.70	62.60	55.70	53.10	63.00	65.00	66.80	75.10	53.40	52.00
K	27.80	28.20	31.10	33.90	35.50	38.10	39.80	37.90	45.70	48.30	52.00	56.60	55.20	60.00	64.60	63.70	63.60	59.80	39.20
L	32.00	31.60	33.50	30.90	37.10	40.10	41.70	42.40	49.60	36.50	38.40	39.40	49.70	40.90	61.50	79.80	80.00	76.40	80.00
M	34.60	35.60	35.90	38.40	41.60	43.90	42.90	45.50	48.60	49.50	49.50	54.80	52.30	53.10	56.00	66.70	69.30	66.80	60.80
N	12.40	9.40	6.80	10.00	8.20	11.50	15.90	21.60	30.90	55.30	58.40	58.60	61.50	62.40	65.60	69.60	76.90	78.80	74.90
O	47.40	49.10	49.00	47.30	48.70	48.40	44.60	46.00	49.50	48.40	48.20	46.70	46.90	45.50	38.50	38.30	45.70	71.60	65.90
P	24.90	24.10	28.40	29.10	38.90	43.40	47.60	52.60	58.70	73.70	72.70	78.50	80.00	80.00	80.00	80.00	80.00	78.10	70.00
Q	13.20	16.50	20.60	22.70	26.90	27.60	33.10	37.10	42.00	49.80	59.00	62.30	58.60	54.20	59.20	65.20	76.80	66.90	73.10
R	21.00	16.60	17.30	19.20	21.90	24.20	27.90	29.90	33.30	34.90	43.70	52.20	54.10	53.30	54.80	63.50	64.80	62.40	52.10
S	32.10	27.30	25.80	23.70	23.10	29.00	36.70	43.80	47.20	53.20	61.80	68.10	66.70	76.00	80.00	80.00	80.00	80.00	80.00
T	21.60	15.60	13.20	14.30	17.80	20.10	22.40	25.10	30.80	34.30	43.10	52.80	61.30	57.70	69.20	65.90	71.70	66.50	51.90

Appendix 3. Results for the auditory-bandwidth experiment.

	P05	P10	P20	V05	V10	V20	D05	D10	D20
a	84.98	88.10	88.76	72.00	77.95	80.85	12.98	10.15	7.90
b	88.37	91.81	88.88	74.68	81.03	84.66	13.68	10.78	4.22
c	87.03	90.98	89.39	71.46	76.68	80.10	15.56	14.29	9.29
d	88.76	88.37	87.61	75.93	78.76	82.22	12.83	9.61	5.39
e	87.32	90.66	90.15	76.95	81.03	85.24	10.37	9.63	4.90
f	91.15	92.85	91.85	75.63	83.37	84.19	15.51	9.49	7.66
g	88.07	89.68	91.61	73.00	81.12	82.68	15.07	8.56	8.93
h	90.49	91.51	91.17	74.76	81.71	84.73	15.73	9.80	6.44
i	88.56	86.90	89.56	73.07	77.66	82.66	15.49	9.24	6.90
j	89.73	87.39	90.24	79.10	81.85	84.46	10.64	5.54	5.78
A	90.34	90.02	90.24	73.34	78.03	82.15	17.00	12.00	8.10
B	91.46	92.05	92.95	81.51	85.29	90.54	9.95	6.76	2.41
C	105.15	105.15	100.15	91.10	96.83	100.12	14.05	8.32	0.03
D	101.27	98.37	95.90	90.24	93.68	97.58	11.02	4.68	-1.68
E	98.81	92.32	92.32	84.63	88.49	91.39	14.17	3.83	0.93
F	100.76	109.98	102.44	90.10	101.66	101.83	10.66	8.32	0.61
G	91.02	90.15	91.71	78.63	80.85	85.10	12.39	9.29	6.61
H	94.17	91.95	90.27	78.54	85.05	86.98	15.63	6.90	3.29
I	90.93	92.76	90.54	78.78	82.00	84.90	12.15	10.76	5.63
J	97.39	101.78	98.68	89.83	97.15	96.39	7.56	4.63	2.29
K	91.00	91.44	92.15	81.10	85.85	89.66	9.90	5.59	2.49
L	88.68	86.78	84.81	74.59	77.02	82.07	14.10	9.76	2.73
M	91.17	88.32	90.12	74.61	80.12	87.93	16.56	8.20	2.20
N	93.95	94.12	94.44	85.17	90.02	93.61	8.78	4.10	0.83
O	91.63	90.42	90.76	78.19	83.54	88.51	13.44	6.88	2.24
P	92.64	93.00	89.93	83.27	88.44	89.76	9.37	4.56	0.17
Q	96.93	97.39	92.73	83.51	86.61	89.39	13.41	10.78	3.34
R	94.27	93.56	92.73	78.81	84.10	87.71	15.46	9.46	5.02
S	89.81	90.98	89.39	79.46	83.73	86.22	10.34	7.24	3.17
T	91.29	91.73	92.39	75.17	81.12	84.78	16.12	10.61	7.61

Appendix 4. Results for the temporal-resolution experiment.

	P05	P10	P15	V05	V10	V15	D05	D10	D15
a	103.49	103.71	105.66	97.07	100.63	103.03	6.41	3.07	2.63
b	103.10	103.78	102.93	97.98	101.46	102.66	5.12	2.32	0.27
c	102.76	105.24	104.61	94.10	100.19	104.15	8.66	5.05	0.46
d	104.66	103.37	103.17	96.34	99.95	103.71	8.32	3.41	−0.54
e	103.93	103.73	105.37	94.78	100.58	102.05	9.15	3.15	3.32
f	104.37	105.93	106.78	95.54	100.76	103.44	8.83	5.17	3.34
g	101.61	103.44	104.02	95.61	97.90	101.12	6.00	5.54	2.90
h	102.59	107.63	110.54	94.78	101.90	109.10	7.80	5.73	1.44
i	100.68	101.61	102.95	94.22	99.00	101.56	6.46	2.61	1.39
j	103.71	104.54	104.51	97.93	102.49	105.02	5.78	2.05	−0.51
A	107.66	106.51	107.15	93.76	99.68	103.78	13.90	6.83	3.37
B	104.29	108.76	110.78	94.83	104.98	109.83	9.46	3.78	0.95
C	102.93	106.32	105.81	96.59	102.76	103.95	6.34	3.56	1.85
D	106.29	107.54	106.51	96.10	104.81	104.68	10.19	2.73	1.83
E	103.44	104.58	104.00	94.88	99.63	102.44	8.56	4.95	1.56
F	109.76	110.76	113.76	94.39	103.22	112.42	15.37	7.54	1.34
G	104.05	103.68	105.32	93.27	99.73	103.46	10.78	3.95	1.85
H	105.12	106.90	104.81	92.73	102.76	105.15	12.39	4.15	−0.34
I	105.29	108.29	104.54	92.05	99.42	102.59	13.24	8.88	1.95
J	108.32	111.37	112.00	104.22	111.63	112.54	4.10	−0.27	−0.54
K	107.78	107.95	105.90	96.95	100.85	103.88	10.83	7.10	2.02
L	104.63	105.83	106.27	94.58	100.49	104.83	10.05	5.34	1.44
M	105.22	109.27	107.34	93.05	99.37	101.85	12.17	9.90	5.49
N	103.85	105.03	104.98	95.42	101.51	103.51	8.44	3.51	1.46
O	108.17	108.49	109.02	98.49	103.76	107.71	9.68	4.73	1.32
P	103.29	103.63	104.10	95.61	100.88	104.54	7.68	2.76	−0.44
Q	105.83	106.10	107.37	97.78	101.03	103.76	8.05	5.07	3.61
R	104.83	103.88	102.98	91.90	95.88	101.42	12.93	8.00	1.56
S	103.88	103.59	102.63	89.83	94.66	100.12	14.05	8.93	2.51
T	105.95	106.42	104.56	92.41	100.49	101.49	13.54	5.93	3.07

Appendix 5. Continuity thresholds (in dB) for 8 tone-noise periods and 8 levels.

	100	200	300	400	500	600	700	800	80	70	60	50	40	30	20	10
a	18.00	24.00	29.00	46.50	54.00	51.50	51.00	50.00	50.00	58.50	83.50	483.50	583.50	592.00	683.50	717.00
b	23.00	30.00	44.00	53.00	54.00	55.00	52.50	51.50	58.50	100.00	192.00	483.50	675.00	675.00	708.50	750.00
c	48.00	44.00	40.00	37.50	34.00	41.50	33.50	31.50	108.50	133.50	91.50	325.00	533.50	641.50	633.50	642.00
d	17.50	21.50	54.50	52.50	50.50	47.50	42.00	26.00	58.50	58.50	66.50	475.00	591.50	616.50	625.00	625.00
e	63.00	61.00	60.50	60.50	63.50	58.50	55.50	50.00	58.50	83.50	533.00	800.00	825.00	800.00	808.50	825.00
f	29.00	35.50	41.50	41.00	47.00	37.50	36.00	32.50	108.00	133.00	191.50	258.50	500.00	575.00	667.00	567.00
g	76.00	54.00	59.50	61.00	57.00	58.50	48.00	44.50	125.00	200.00	416.50	708.50	808.50	750.00	791.50	775.00
h	40.00	53.50	53.50	54.00	47.50	50.00	45.00	47.50	75.00	58.50	100.00	658.50	767.00	758.50	733.50	758.50
i	49.00	57.00	63.50	67.00	69.50	65.00	71.50	57.50	133.00	442.00	591.50	716.50	750.00	783.00	783.50	792.00
j	69.00	70.00	69.50	61.50	52.50	51.00	51.00	47.50	258.00	325.00	533.50	675.00	716.50	741.50	716.50	750.00
A	83.50	63.00	51.50	51.50	44.50	41.50	36.50	40.50	192.00	208.00	258.50	558.50	683.50	733.50	692.00	808.50
B	56.00	54.00	54.50	52.50	53.50	47.50	46.50	36.00	50.00	50.00	75.00	775.00	741.50	733.50	775.00	800.00
C	38.50	38.50	49.50	46.00	52.50	49.00	50.00	52.50	100.00	233.50	316.50	491.50	550.00	616.50	683.50	766.50
D	68.50	45.00	37.50	40.00	41.50	39.50	34.50	30.00	108.50	166.50	242.00	366.50	350.00	608.50	766.50	750.00
E	47.50	47.50	47.50	48.50	39.00	40.00	36.00	32.50	50.00	91.50	158.00	408.00	616.50	667.00	683.00	708.00
F	68.00	44.00	28.00	24.00	17.50	28.50	20.00	20.00	100.00	142.00	175.00	283.50	325.00	350.00	433.50	700.00
G	27.00	41.00	51.50	51.00	49.00	52.50	48.00	44.00	75.00	66.50	58.50	583.00	650.00	633.00	766.50	808.50
H	56.50	52.50	51.50	46.00	40.00	35.00	26.00	32.50	67.00	67.00	133.00	650.00	675.00	600.00	566.50	642.00
I	56.50	52.50	50.00	57.00	52.00	49.00	48.00	46.00	92.00	100.00	116.50	708.00	791.50	733.00	791.50	775.00
J	61.50	63.50	55.50	56.00	46.50	40.00	40.00	41.50	125.00	150.00	350.00	583.50	700.00	691.50	691.50	758.50
K	54.50	54.00	54.50	50.00	53.50	49.50	47.00	42.50	108.00	83.50	158.50	733.50	725.00	750.00	758.00	725.00
L	52.50	32.50	24.50	19.50	20.50	21.00	21.50	24.50	125.00	125.00	183.00	216.50	250.00	300.00	408.50	550.00
M	37.50	37.50	31.50	30.00	29.00	36.00	24.50	32.00	92.00	67.00	150.00	200.00	308.00	366.50	700.00	692.00
N	64.00	54.00	54.50	57.50	58.50	44.00	37.50	45.00	66.50	83.00	350.00	700.00	708.50	758.00	758.50	725.00
O	55.00	56.00	52.50	52.50	50.00	47.00	38.50	37.50	75.00	100.00	183.00	575.00	741.50	716.50	700.00	792.00
P	54.00	53.50	52.50	55.00	52.50	52.50	45.50	41.00	66.50	58.50	83.00	741.50	758.50	775.00	800.00	783.50
Q	58.50	57.50	54.00	52.00	53.50	44.00	40.00	37.50	92.00	116.50	308.50	625.00	617.00	692.00	758.50	758.00
R	66.00	50.00	46.50	49.50	46.00	48.50	44.00	43.50	58.50	125.00	166.50	500.00	791.50	775.00	717.00	800.00
S	39.00	30.00	32.00	31.00	26.50	26.00	26.50	21.00	50.00	58.50	75.00	108.50	158.50	316.50	750.00	800.00
T	74.50	46.50	34.50	21.50	13.50	15.00	13.00	11.00	158.50	142.00	225.00	241.50	275.00	258.00	350.00	642.00

Appendix 6. Masked thresholds of short noise probes in the frequency-sweep experiment.

	H00	H05	H10	H15	H20	H25	H30	H40	H50	H60	F00	F05	F10	F15	F20	F30	F40	F60	F90	F120
a	-3.50	3.90	4.20	10.00	10.10	16.00	14.30	15.30	17.10	20.50	-5.70	-3.30	-1.40	3.20	5.10	9.90	14.40	19.90	19.10	17.70
b	-3.40	-0.80	4.90	4.90	8.90	10.10	13.10	11.60	12.60	13.40	-3.10	-0.20	3.30	3.80	8.90	9.90	11.20	17.30	17.40	12.90
c	-2.80	0.10	2.80	9.00	8.60	10.50	13.70	16.50	16.80	19.40	-3.20	1.90	1.30	4.60	4.50	7.50	13.20	18.80	20.50	19.20
d	-2.40	-1.00	3.50	8.60	8.50	9.60	8.40	13.40	14.70	17.50	-3.00	2.90	3.60	6.50	7.50	8.10	10.30	13.50	18.20	17.20
e	5.20	4.30	7.30	8.90	13.40	15.10	13.60	18.70	16.30	17.00	4.60	3.40	7.60	6.40	11.60	15.10	14.10	14.70	19.10	22.10
f	2.40	5.30	7.90	8.40	11.70	15.40	17.90	24.40	19.90	24.00	3.50	3.00	3.10	6.20	6.10	12.90	12.10	15.80	20.90	22.40
g	0.30	4.90	6.00	10.50	10.20	14.50	13.40	16.60	19.20	21.50	-5.70	-0.80	0.60	6.00	5.40	12.50	13.10	16.80	16.10	20.40
h	-1.80	-0.70	4.30	7.10	8.60	13.20	13.60	16.30	17.30	15.70	-1.00	1.40	1.40	2.20	4.70	7.00	13.00	16.30	22.80	23.90
i	-6.80	-1.70	-1.30	1.10	5.20	7.30	3.10	13.70	12.20	11.30	-0.90	-4.80	-0.10	1.20	1.30	6.70	11.10	13.20	12.30	12.40
j	-0.70	3.90	7.60	6.80	10.00	15.20	13.90	15.10	19.00	18.40	4.80	5.50	7.70	7.30	12.70	15.80	13.30	20.90	15.50	18.30
A	-5.60	2.40	14.10	21.40	23.90	28.10	28.20	27.90	29.70	28.60	-1.30	-0.70	8.10	11.70	16.70	21.20	27.00	28.00	29.30	29.20
B	-1.70	2.60	8.50	10.80	14.20	23.20	22.10	26.10	24.60	26.20	-1.60	5.50	10.50	6.90	11.80	15.40	16.50	22.40	19.90	20.20
C	-5.20	6.40	11.20	13.60	16.10	17.90	19.30	23.20	24.50	27.00	2.90	5.00	7.40	10.50	9.90	13.30	15.40	19.90	24.70	23.60
D	8.80	5.90	14.50	20.20	19.70	24.50	25.30	23.90	24.50	27.80	10.40	10.70	14.50	18.50	19.30	22.60	25.10	25.50	26.60	25.30
E	-2.90	-1.10	5.70	6.80	10.20	11.70	13.90	12.40	15.40	17.70	-2.30	-1.50	1.80	1.70	0.60	4.90	10.90	10.80	13.60	14.60
F	-9.10	-0.70	8.70	15.20	24.50	24.50	25.50	26.00	24.40	24.30	-2.20	0.40	5.50	9.30	15.10	22.30	22.40	23.80	24.20	25.60
G	-9.80	-4.80	1.30	7.30	9.80	13.70	13.00	19.00	14.70	19.40	-5.20	-2.30	4.10	5.60	6.30	10.60	11.80	16.00	20.60	19.90
H	-6.40	0.10	1.70	8.80	14.10	16.10	17.50	19.40	22.70	26.60	-6.00	1.60	7.20	7.40	8.70	15.70	23.90	26.00	27.70	27.90
I	-8.00	-3.00	0.00	4.70	11.70	17.60	14.50	20.00	20.00	23.50	-4.40	-4.90	-0.10	1.40	6.90	8.00	13.60	17.40	18.70	18.70
J	-0.30	3.70	9.50	18.10	23.40	23.90	28.10	29.20	29.20	28.40	0.80	2.20	10.50	13.80	19.80	24.10	29.50	27.60	29.00	29.10
K	-0.60	6.40	7.60	12.80	19.60	22.00	25.70	24.00	26.50	26.20	4.50	6.70	12.40	15.80	16.20	19.80	20.40	25.10	22.00	22.30
L	-4.70	-3.10	1.10	8.50	17.30	19.70	20.10	20.80	21.80	20.00	-4.30	0.30	1.90	6.50	7.00	12.00	17.00	20.90	27.20	25.80
M	-3.60	-0.60	3.90	6.30	14.80	16.00	17.40	17.50	15.50	13.80	-3.30	0.00	2.70	3.90	6.10	6.60	11.50	16.50	15.10	12.00
N	-8.10	-0.80	2.00	8.30	12.00	8.80	14.30	16.10	16.80	17.70	-7.10	-5.10	2.20	1.50	1.70	8.70	12.20	13.70	21.40	16.60
O	-1.30	8.00	14.10	16.50	17.90	17.80	20.60	20.70	22.70	24.10	-0.80	3.50	14.60	15.30	21.80	24.00	25.50	29.30	27.70	23.00
P	6.50	7.70	9.70	10.20	13.40	15.60	14.10	14.40	15.80	12.30	5.60	8.50	8.40	7.10	9.80	10.70	10.30	12.20	16.50	14.40
Q	-0.50	2.00	9.10	12.50	16.00	18.90	21.00	20.50	23.90	19.20	2.70	6.20	7.50	10.50	13.00	17.30	18.00	19.00	19.90	16.30
R	-12.00	-0.30	4.80	9.70	8.90	14.00	17.80	17.20	20.70	19.70–	11.10	2.30	8.20	11.10	14.30	14.50	14.60	16.70	20.40	20.90
S	-9.70	-1.10	5.60	7.70	12.90	16.70	17.70	23.60	22.40	20.80	-8.70	-4.00	3.80	6.60	7.30	14.00	18.00	25.90	26.10	28.80
T	-4.80	3.10	6.40	11.00	17.40	14.90	15.90	15.70	19.30	21.70	-3.40	9.30	14.30	16.00	17.40	21.30	17.60	13.30	7.90	4.30

Appendix 7. Speech-reception thresholds in 10 listening conditions.

	SIL	F75	F85	F95	T65	T75	T85	C65	C75	C85
a	20.40	32.20	38.80	48.80	43.60	49.80	55.20	59.40	69.60	79.80
b	16.20	30.40	43.60	54.20	42.00	47.60	52.40	59.80	69.40	80.80
c	19.00	35.80	44.00	53.60	40.00	49.80	53.80	60.20	70.20	80.20
d	16.40	33.60	37.00	55.20	42.60	48.00	55.80	60.60	70.00	80.00
e	14.00	39.40	51.00	63.60	41.00	50.20	57.80	61.80	72.00	80.80
f	10.40	35.80	50.20	67.40	39.80	44.60	54.00	60.20	71.00	81.20
g	13.60	32.20	45.60	55.60	38.20	48.00	51.00	60.80	70.20	80.40
h	19.80	33.20	50.00	61.80	44.60	45.60	56.60	59.80	70.80	81.60
i	13.80	32.60	46.40	58.60	40.00	49.00	52.60	59.40	70.00	80.00
j	11.00	31.80	38.40	55.00	42.20	47.40	50.40	60.80	71.80	81.80
A	51.00	53.80	57.40	60.20	60.00	64.20	71.60	62.00	73.60	82.20
B	59.80	63.60	71.80	74.80	65.00	70.40	78.60	65.60	73.60	81.60
C	43.20	54.80	56.00	70.60	59.80	68.60	77.40	62.40	73.20	85.20
D	55.20	58.60	62.40	72.40	64.60	75.00	81.00	67.40	76.20	87.40
E	33.40	40.80	44.80	54.00	59.60	71.00	76.40	67.00	76.20	83.60
F	55.60	68.60	74.00	83.20	65.80	73.60	86.00	68.40	78.20	90.60
G	34.60	57.00	64.20	71.80	61.80	65.00	70.40	62.40	72.60	82.40
H	47.40	63.40	69.60	80.80	60.00	69.80	72.80	65.20	72.80	82.60
I	49.60	58.60	62.20	66.40	63.60	68.80	75.80	64.80	74.00	81.00
J	53.00	58.60	63.20	64.80	61.20	66.40	76.00	64.80	74.20	87.00
K	57.20	60.60	66.20	72.20	63.40	68.80	74.00	63.40	72.80	82.80
L	53.00	59.20	62.40	68.20	61.40	68.60	72.80	63.40	71.80	81.80
M	55.80	63.40	70.80	73.80	63.20	67.20	77.00	62.80	71.80	82.00
N	37.20	57.40	60.80	68.60	57.40	67.40	74.80	63.80	72.40	83.60
O	49.40	53.20	56.80	64.20	57.20	64.20	70.40	60.00	71.40	80.40
P	62.40	69.00	70.20	70.80	73.00	78.20	83.60	71.20	75.20	87.20
Q	52.80	57.40	64.60	72.60	62.80	70.60	74.40	62.40	73.20	83.40
R	46.60	58.80	63.80	79.20	60.60	67.60	75.00	62.80	72.40	82.80
S	53.60	60.80	62.40	70.80	62.00	70.20	79.20	64.80	74.60	82.60
T	45.60	59.20	63.40	74.00	57.60	67.60	73.40	64.20	72.20	84.20

Appendix 8. Percentages of correct responses for initial unvoiced consonants.

A	1	2	3	4	5	6	7	8	9	10	11	12	13
a	96.30	51.85	92.59	25.93	37.04	100.00	33.33	92.59	88.89	74.07	66.67	92.59	100.00
b	100.00	48.15	66.67	51.85	29.63	55.56	40.74	96.30	92.59	29.63	81.48	77.78	85.19
c	85.19	33.33	70.37	11.11	22.22	74.07	14.81	77.78	70.37	29.63	55.56	48.15	55.56
d	81.48	29.63	70.37	29.63	37.04	77.78	22.22	74.07	70.37	14.81	29.63	51.85	85.19
e	88.89	51.85	66.67	7.41	3.70	85.19	48.15	88.89	70.37	11.11	77.78	74.07	85.19
f	100.00	44.44	77.78	51.85	37.04	88.89	33.33	85.19	96.30	40.74	70.37	77.78	96.30
g	92.59	25.93	92.59	7.41	11.11	85.19	25.93	92.59	96.30	33.33	44.44	77.78	96.30
h	92.59	33.33	77.78	22.22	18.52	66.67	25.93	81.48	96.30	29.63	88.89	77.78	81.48
i	96.30	25.93	51.85	14.81	14.81	81.48	37.04	81.48	88.89	18.52	44.44	44.44	88.89
j	92.59	22.22	88.89	25.93	33.33	81.48	51.85	92.59	96.30	25.93	85.19	77.78	96.30
A	70.37	22.22	48.15	0.00	33.33	55.56	37.04	66.67	59.26	22.22	55.56	51.85	70.37
B	70.37	33.33	33.33	48.15	37.04	40.74	37.04	48.15	59.26	33.33	44.44	33.33	48.15
C	51.85	14.81	40.74	22.22	29.63	33.33	14.81	59.26	48.15	25.93	7.41	33.33	48.15
D	81.48	22.22	51.85	40.74	14.81	66.67	25.93	85.19	74.07	25.93	51.85	59.26	74.07
E	74.07	33.33	66.67	37.04	40.74	59.26	40.74	77.78	70.37	37.04	44.44	25.93	44.44
F	66.67	44.44	59.26	22.22	25.93	44.44	29.63	74.07	48.15	25.93	33.33	37.04	48.15
G	96.30	37.04	81.48	29.63	22.22	74.07	33.33	96.30	92.59	55.56	74.07	70.37	66.67
H	70.37	14.81	37.04	18.52	18.52	62.96	29.63	66.67	55.56	14.81	18.52	37.04	70.37
I	59.26	37.04	29.63	48.15	29.63	33.33	29.63	48.15	37.04	29.63	33.33	29.63	51.85
J	96.30	33.33	77.78	14.81	37.04	96.30	44.44	100.00	88.89	11.11	70.37	85.19	96.30
K	44.44	25.93	37.04	18.52	40.74	37.04	33.33	44.44	48.15	14.81	25.93	37.04	51.85
L	25.93	11.11	22.22	22.22	18.52	25.93	11.11	18.52	7.41	18.52	18.52	11.11	22.22
M	88.89	14.81	81.48	14.81	25.93	81.48	44.44	77.78	74.07	18.52	66.67	70.37	66.67
N	59.26	29.63	29.63	3.70	25.93	44.44	29.63	51.85	40.74	18.52	33.33	37.04	44.44
O	59.26	29.63	59.26	25.93	29.63	62.96	25.93	66.67	48.15	11.11	22.22	59.26	66.67
P	59.26	18.52	37.04	14.81	29.63	59.26	18.52	62.96	48.15	18.52	25.93	33.33	55.56
Q	88.89	51.85	55.56	48.15	22.22	62.96	55.56	85.19	70.37	22.22	48.15	48.15	66.67
R	74.07	18.52	51.85	37.04	29.63	55.56	14.81	59.26	51.85	11.11	37.04	33.33	59.26
S	33.33	18.52	44.44	11.11	18.52	37.04	25.93	44.44	29.63	11.11	14.81	25.93	33.33
T	100.00	40.74	85.19	29.63	33.33	62.96	37.04	81.48	92.59	29.63	59.26	62.96	81.48

Appendix 9. Percentages of correct responses for initial voiced consonants.

B	1	2	3	4	5	6	7	8	9	10	11	12	13
a	100.00	61.11	61.11	44.44	22.22	83.33	88.89	100.00	100.00	55.56	77.78	100.00	94.44
b	100.00	33.33	94.44	16.67	50.00	88.89	66.67	100.00	100.00	50.00	88.89	94.44	100.00
c	94.44	44.44	72.22	44.44	50.00	77.78	77.78	94.44	83.33	11.11	44.44	55.56	94.44
d	94.44	27.78	72.22	0.00	27.78	72.22	16.67	88.89	94.44	16.67	61.11	50.00	100.00
e	88.89	61.11	94.44	33.33	33.33	100.00	61.11	100.00	94.44	22.22	94.44	100.00	94.44
f	83.33	16.67	77.78	33.33	38.89	66.67	11.11	83.33	83.33	33.33	83.33	66.67	72.22
g	83.33	38.89	83.33	61.11	61.11	94.44	38.89	83.33	77.78	50.00	27.78	66.67	88.89
h	100.00	50.00	100.00	44.44	44.44	94.44	61.11	100.00	100.00	33.33	100.00	100.00	88.89
i	88.89	44.44	66.67	44.44	38.89	72.22	50.00	83.33	66.67	38.89	61.11	66.67	61.11
j	100.00	38.89	66.67	22.22	50.00	94.44	44.44	100.00	83.33	11.11	88.89	83.33	94.44
A	77.78	5.56	66.67	0.00	0.00	72.22	22.22	83.33	61.11	0.00	11.11	44.44	55.56
B	77.78	27.78	44.44	11.11	0.00	50.00	22.22	88.89	61.11	0.00	33.33	44.44	55.56
C	50.00	33.33	50.00	27.78	16.67	55.56	27.78	55.56	61.11	16.67	38.89	72.22	44.44
D	83.33	16.67	55.56	27.78	22.22	61.11	22.22	61.11	61.11	33.33	55.56	77.78	61.11
E	66.67	16.67	44.44	22.22	33.33	61.11	33.33	55.56	61.11	16.67	50.00	50.00	55.56
F	66.67	27.78	55.56	5.56	5.56	72.22	38.89	61.11	83.33	22.22	5.56	44.44	72.22
G	88.89	11.11	55.56	16.67	22.22	61.11	66.67	66.67	94.44	11.11	44.44	66.67	61.11
H	83.33	55.56	72.22	16.67	11.11	61.11	33.33	66.67	88.89	27.78	50.00	50.00	77.78
I	66.67	16.67	55.56	16.67	22.22	66.67	55.56	72.22	38.89	11.11	50.00	44.44	72.22
J	100.00	61.11	77.78	55.56	22.22	94.44	33.33	100.00	77.78	44.44	44.44	77.78	94.44
K	72.22	33.33	61.11	33.33	27.78	66.67	50.00	83.33	50.00	16.67	38.89	16.67	50.00
L	22.22	38.89	44.44	33.33	22.22	33.33	27.78	44.44	11.11	22.22	22.22	22.22	16.67
M	100.00	94.44	88.89	38.89	50.00	88.89	66.67	88.89	94.44	44.44	88.89	72.22	77.78
N	72.22	16.67	50.00	27.78	16.67	38.89	27.78	66.67	61.11	5.56	44.44	50.00	61.11
O	72.22	11.11	55.56	11.11	22.22	50.00	16.67	61.11	72.22	0.00	33.33	44.44	72.22
P	66.67	27.78	66.67	22.22	16.67	61.11	55.56	72.22	77.78	55.56	50.00	16.67	55.56
Q	83.33	100.00	72.22	44.44	27.78	66.67	100.00	88.89	94.44	27.78	55.56	77.78	77.78
R	66.67	66.67	72.22	44.44	33.33	33.33	50.00	77.78	66.67	44.44	27.78	22.22	50.00
S	44.44	27.78	22.22	61.11	27.78	11.11	33.33	44.44	44.44	27.78	27.78	38.89	22.22
T	100.00	61.11	77.78	27.78	27.78	66.67	72.22	100.00	88.89	22.22	44.44	77.78	77.78

Appendix 10. Percentages of correct responses for medial unvoiced consonants.

C	1	2	3	4	5	6	7	8	9	10	11	12	13
a	96.30	81.48	88.89	55.56	55.56	96.30	40.74	88.89	100.00	85.19	70.37	96.30	88.89
b	100.00	66.67	96.30	51.85	66.67	96.30	62.96	100.00	96.30	59.26	85.19	92.59	92.59
c	92.59	44.44	66.67	37.04	33.33	96.30	37.04	88.89	74.07	29.63	29.63	51.85	40.74
d	96.30	51.85	74.07	33.33	44.44	92.59	37.04	85.19	92.59	40.74	37.04	62.96	66.67
e	96.30	77.78	85.19	51.85	48.15	88.89	66.67	96.30	77.78	22.22	70.37	77.78	81.48
f	96.30	48.15	88.89	70.37	66.67	92.59	51.85	85.19	92.59	51.85	22.22	66.67	77.78
g	96.30	70.37	81.48	59.26	62.96	85.19	59.26	96.30	88.89	55.56	7.41	74.07	74.07
h	100.00	55.56	100.00	44.44	44.44	96.30	44.44	92.59	100.00	59.26	85.19	96.30	88.89
i	96.30	70.37	70.37	25.93	51.85	92.59	70.37	92.59	88.89	51.85	33.33	55.56	33.33
j	100.00	74.07	66.67	62.96	70.37	92.59	77.78	85.19	92.59	55.56	48.15	81.48	40.74
A	70.37	40.74	55.56	50.00	48.15	81.48	44.44	74.07	77.78	22.22	40.74	51.85	70.37
B	77.78	48.15	33.33	22.22	48.15	48.15	37.04	66.67	48.15	37.04	18.52	59.26	44.44
C	66.67	37.04	33.33	18.52	29.63	40.74	18.52	29.63	33.33	25.93	29.63	18.52	22.22
D	85.19	29.63	48.15	14.81	33.33	70.37	22.22	66.67	62.96	40.74	55.56	81.48	70.37
E	77.78	44.44	74.07	44.44	55.56	51.85	40.74	74.07	81.48	66.67	48.15	40.74	51.85
F	77.78	59.26	70.37	29.63	37.04	66.67	44.44	74.07	59.26	66.67	14.81	22.22	62.96
G	92.59	51.85	81.48	44.44	44.44	88.89	48.15	77.78	81.48	22.22	33.33	44.44	51.85
H	59.26	37.04	37.04	44.44	14.81	40.74	25.93	48.15	37.04	48.15	25.93	14.81	44.44
I	62.96	40.74	25.93	33.33	37.04	33.33	29.63	44.44	40.74	33.33	29.63	37.04	51.85
J	96.30	74.07	85.19	37.04	59.26	96.30	88.89	100.00	77.78	29.63	74.07	88.89	96.30
K	59.26	33.33	40.74	33.33	40.74	37.04	44.44	70.37	18.52	33.33	25.93	22.22	33.33
L	22.22	25.93	25.93	11.11	22.22	33.33	14.81	37.04	29.63	29.63	14.81	11.11	25.93
M	96.30	51.85	81.48	55.56	55.56	88.89	44.44	85.19	62.96	37.04	40.74	74.07	66.67
N	62.96	51.85	25.93	22.22	33.33	48.15	33.33	59.26	62.96	59.26	11.11	25.93	48.15
O	62.96	40.74	55.56	14.81	33.33	62.96	37.04	74.07	48.15	18.52	29.63	22.22	59.26
P	74.07	44.44	22.22	25.93	29.63	48.15	29.63	70.37	48.15	22.22	18.52	40.74	59.26
Q	77.78	77.78	77.78	66.67	70.37	88.89	70.37	85.19	66.67	33.33	25.93	55.56	55.56
R	85.19	62.96	81.48	44.44	55.56	92.59	33.33	74.07	25.93	22.22	40.74	44.44	48.15
S	77.78	29.63	59.26	25.93	40.74	81.48	37.04	66.67	48.15	59.26	29.63	33.33	59.26
T	92.59	48.15	92.59	37.04	59.26	81.48	40.74	77.78	96.30	44.44	44.44	59.26	66.67

Appendix 11. Percentages of correct responses for medial voiced consonants.

D	1	2	3	4	5	6	7	8	9	10	11	12	13
a	100.00	94.44	66.67	22.22	61.11	94.44	77.78	100.00	88.89	83.33	66.67	100.00	94.44
b	94.44	66.67	83.33	22.22	50.00	72.22	66.67	94.44	94.44	44.44	77.78	88.89	100.00
c	88.89	88.89	72.22	27.78	66.67	88.89	66.67	88.89	72.22	55.56	50.00	72.22	72.22
d	100.00	88.89	83.33	5.56	66.67	94.44	16.67	66.67	100.00	83.33	27.78	22.22	88.89
e	94.44	94.44	88.89	33.33	27.78	100.00	77.78	100.00	94.44	33.33	66.67	100.00	88.89
f	100.00	66.67	88.89	38.89	55.56	77.78	38.89	77.78	100.00	44.44	61.11	55.56	88.89
g	100.00	61.11	100.00	16.67	38.89	100.00	44.44	94.44	100.00	77.78	33.33	66.67	94.44
h	100.00	83.33	100.00	38.89	33.33	100.00	50.00	94.44	100.00	50.00	83.33	94.44	88.89
i	100.00	55.56	72.22	27.78	38.89	94.44	55.56	94.44	77.78	27.78	27.78	66.67	66.67
j	100.00	55.56	44.44	16.67	50.00	94.44	55.56	100.00	88.89	22.22	61.11	55.56	33.33
A	77.78	55.56	61.11	66.67	38.89	88.89	38.89	50.00	72.22	55.56	44.44	44.44	61.11
B	83.33	27.78	44.44	11.11	0.00	61.11	16.67	77.78	44.44	5.56	38.89	38.89	33.33
C	55.56	27.78	50.00	38.89	0.00	55.56	33.33	61.11	55.56	38.89	22.22	33.33	44.44
D	61.11	33.33	44.44	44.44	22.22	61.11	11.11	72.22	83.33	27.78	50.00	66.67	50.00
E	77.78	44.44	55.56	22.22	5.56	55.56	22.22	50.00	50.00	22.22	38.89	27.78	27.78
F	72.22	61.11	72.22	0.00	27.78	66.67	11.11	83.33	83.33	55.56	27.78	55.56	66.67
G	94.44	72.22	83.33	11.11	11.11	83.33	5.56	72.22	88.89	66.67	50.00	66.67	55.56
H	77.78	16.67	38.89	16.67	27.78	50.00	11.11	66.67	33.33	5.56	0.00	38.89	22.22
I	44.44	38.89	44.44	22.22	11.11	22.22	11.11	44.44	38.89	27.78	55.56	27.78	50.00
J	100.00	55.56	66.67	11.11	11.11	83.33	61.11	100.00	66.67	61.11	38.89	55.56	88.89
K	72.22	55.56	66.67	38.89	22.22	61.11	38.89	77.78	38.89	22.22	27.78	33.33	55.56
L	22.22	5.56	11.11	44.44	38.89	11.11	33.33	16.67	22.22	16.67	11.11	22.22	22.22
M	83.33	77.78	72.22	27.78	55.56	88.89	77.78	83.33	55.56	38.89	16.67	38.89	55.56
N	61.11	0.00	33.33	0.00	5.56	50.00	5.56	44.44	50.00	22.22	22.22	66.67	55.56
O	83.33	72.22	66.67	11.11	16.67	61.11	33.33	83.33	38.89	22.22	16.67	44.44	72.22
P	77.78	44.44	44.44	0.00	38.89	61.11	16.67	55.56	38.89	38.89	61.11	33.33	44.44
Q	94.44	100.00	55.56	72.22	33.33	77.78	88.89	83.33	88.89	22.22	27.78	77.78	72.22
R	83.33	72.22	66.67	38.89	33.33	50.00	11.11	83.33	55.56	27.78	22.22	5.56	38.89
S	61.11	38.89	11.11	27.78	33.33	11.11	22.22	38.89	22.22	11.11	16.67	11.11	22.22
T	94.44	88.89	88.89	55.56	61.11	72.22	61.11	66.67	94.44	77.78	66.67	72.22	77.78

Appendix 12. Percentages of correct responses for final unvoiced consonants.

E	1	2	3	4	5	6	7	8	9	10	11	12	13
a	88.89	62.22	82.22	46.67	57.78	91.11	51.11	91.11	88.89	75.56	82.22	97.78	91.11
b	100.00	66.67	93.33	35.56	71.11	86.67	71.11	91.11	97.78	46.67	88.89	91.11	97.78
c	95.56	73.33	77.78	42.22	62.22	91.11	55.56	93.33	80.00	46.67	77.78	75.56	75.56
d	100.00	62.22	88.89	33.33	68.89	91.11	33.33	77.78	100.00	73.33	37.78	80.00	91.11
e	93.33	82.22	93.33	57.78	64.44	97.78	46.67	91.11	88.89	44.44	82.22	91.11	86.67
f	93.33	64.44	88.89	55.56	66.67	88.89	53.33	93.33	93.33	64.44	48.89	86.67	75.56
g	95.56	62.22	95.56	42.22	68.89	97.78	37.78	93.33	97.78	62.22	28.89	91.11	91.11
h	97.78	80.00	93.33	55.56	66.67	91.11	62.22	80.00	97.78	71.11	93.33	95.56	84.44
i	100.00	71.11	86.67	33.33	75.56	93.33	48.89	95.56	84.44	62.22	35.56	82.22	71.11
j	97.78	71.11	82.22	64.44	82.22	97.78	64.44	97.78	93.33	55.56	84.44	97.78	82.22
A	77.78	46.67	64.44	20.00	44.44	82.22	57.78	75.56	55.56	64.44	46.67	68.89	42.22
B	53.33	53.33	44.44	35.56	42.22	55.56	40.00	51.11	46.67	44.44	26.67	48.89	40.00
C	33.33	24.44	35.56	37.78	33.33	35.56	28.89	42.22	42.22	51.11	31.11	35.56	40.00
D	60.00	42.22	53.33	42.22	28.89	51.11	40.00	57.78	62.22	53.33	46.67	66.67	51.11
E	68.89	60.00	60.00	33.33	64.44	44.44	48.89	57.78	57.78	42.22	42.22	53.33	42.22
F	55.56	53.33	46.67	44.44	35.56	53.33	44.44	55.56	62.22	60.00	40.00	53.33	46.67
G	73.33	68.89	80.00	42.22	40.00	71.11	44.44	60.00	66.67	40.00	24.44	55.56	42.22
H	46.67	46.67	40.00	37.78	51.11	51.11	35.56	55.56	42.22	20.00	31.11	44.44	37.78
I	42.22	44.44	33.33	33.33	33.33	51.11	33.33	42.22	28.89	33.33	33.33	33.33	37.78
J	93.33	75.56	77.78	46.67	68.89	100.00	66.67	86.67	80.00	55.56	71.11	77.78	84.44
K	57.78	44.44	60.00	42.22	44.44	62.22	31.11	64.44	35.56	40.00	35.56	24.44	48.89
L	37.78	37.78	37.78	37.78	44.44	44.44	46.67	28.89	46.67	28.89	28.89	35.56	33.33
M	86.67	64.44	84.44	37.78	51.11	88.89	62.22	93.33	68.89	46.67	35.56	66.67	68.89
N	48.89	44.44	44.44	28.89	46.67	62.22	40.00	37.78	44.44	46.67	35.56	40.00	40.00
O	62.22	46.67	44.44	24.44	48.89	51.11	35.56	57.78	37.78	37.78	48.89	42.22	51.11
P	62.22	48.89	51.11	37.78	48.89	46.67	44.44	51.11	44.44	40.00	44.44	48.89	40.00
Q	77.78	75.56	71.11	53.33	46.67	73.33	62.22	66.67	80.00	35.56	44.44	66.67	64.44
R	88.89	62.22	71.11	71.11	62.22	73.33	44.44	55.56	51.11	48.89	53.33	48.89	46.67
S	55.56	37.78	53.33	33.33	40.00	51.11	44.44	66.67	46.67	42.22	40.00	37.78	46.67
T	88.89	77.78	82.22	51.11	68.89	77.78	51.11	80.00	86.67	73.33	71.11	73.33	57.78

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CURRICULUM VITAE

De schrijver van dit proefschrift werd op 19 januari 1955 in Eindhoven geboren. Na het behalen van het Gymnasium-ß diploma aan het Lyceum Augustinianum in 1973 in Eindhoven, maakte hij een aanvang met de studie Technische Natuurkunde aan de Technische Universiteit in Eindhoven. Op 14 maart 1979 legde hij het ingenieursexamen met goed gevolg af.

Vervolgens was hij tot eind 1980 als wetenschappelijk medewerker verbonden aan de afdeling Audiologie van het Instituut voor Zintuigfysiologie (TNO) in Soesterberg, in eerste instantie (tot juli 1980) in het kader van detachering in militaire dienst, daarna in dienst van TNO.

Op 1 januari 1981 werd het onderzoek verricht waarvan in dit proefschrift verantwoording afgelegd is. Het onderzoek werd uitgevoerd in de groep Experimentele Audiologie van de vakgroep KNO van het Academisch Ziekenhuis der Vrije Universiteit in Amsterdam, financieel mogelijk gemaakt door de Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO).

Op 1 januari 1985 trad hij in dienst van de afdeling KNO van het Academisch Ziekenhuis in Leiden als klinisch audioloog. Sindsdien is hij in deze kliniek werkzaam als hoofd van het Audiologisch Centrum.

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Stellingen behorende bij het Proefschrift

THE PERCEPTION OF FLUCTUATING SOUNDS BY HEARING-IMPAIRED LISTENERS

J.A.P.M. de Laat

1 Veel slechthorenden kunnen korte muzikale melodieën in een meerstemmige context minder goed herkennen dan verklaard kan worden op grond van de spectrale en de temporele resolutie van het gehoor (dit proefschrift, hoofdstuk 4).

2 Vanwege het belang van de perceptie door slechthorenden van de overgang van klinker naar medeklinker en omgekeerd is het gewenst die overgang zo natuurgetrouw mogelijk door middel van het hoortoestel versterkt aan het oor aan te bieden (dit proefschrift, hoofdstuk 5).

3 Voor het vaststellen van de handicap van een slechthorende en het effect van het gebruik van een hoortoestel dient niet alleen de gemiddelde gehoordrempel voor zuivere tonen in stilte te worden bepaald, maar ook de spraakverstaanvaardigheidsdrempel in ruis (dit proefschrift, hoofdstuk 6).

4 De achteruitgang in het verstaan van spraak in ruis door slechthorenden is niet voldoende te verklaren op grond van parameters die de perceptie van statische signalen beschrijven, zoals de gehoordrempel voor zuivere tonen, de spectrale en de temporele resolutie (Dreschler, proefschrift V.U. Amsterdam, 1983), evenmin op basis van parameters die de perceptie van dynamische signalen beschrijven, zoals de continuiteitsdrempel, de maskeerdrempel voor korte ruisstootjes door langere toonstootjes met stijgende frequentie en de melodieherkenningsdrempel (dit proefschrift, hoofdstuk 7).

5 Het verdient aanbeveling om bij loketten in ruimten met veel geroezemoes, zoals postkantoor, stationshal en bankinstelling, een ringleidingsysteem voor slechthorenden aan te leggen.

6 Als de spreiding van de resultaten van de twee experimenten met als parameters frequentiediscriminatie en woordidentificatie, waar zowel normaal- als slechthorenden aan deelgenomen hebben, niet gaussisch verdeeld is, is het statistisch onverantwoord correlatie-coëfficiënten te berekenen voor de niet-homogene groep slechthorenden en normaalhorenden samen (Tyler, Wood en Fernandes, J.A.S.A. 74 (1983), 1190-1199).

7 Sinds de Barok zijn de opvattingen van Westerse musici over consonantie en welluidendheid ("pleasantness") steeds verder van elkaar verwijderd (Plomp en Levelt, J.A.S.A. 38 (1965), 548-560).

8 Vanwege het verkeerslawaai kan het gebruik van "het fluitje" door een verkeersagent nauwelijks effect hebben op het verkeersgedrag van automobilisten.

9 Het verdient niet alleen aanbeveling dat auteurs van artikelen in vaktijdschriften niet weten door wie hun artikel beoordeeld wordt, maar ook dat degenen die het artikel beoordelen niet op de hoogte zijn van de namen van de auteurs.

10 De tijdens promotieplechtigheden door opponenten gedane beloften over bepaalde gedeelten van het proefschrift nog eens met de promovendus van gedachten te wisselen, zouden vaker gestand gedaan moeten worden.

Amsterdam, 6 juni 1989.