

## Pulse coding in the ensemble of peripheral fibres and auditory discrimination of the tone burst intensity

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### ABSTRACT

The intensity discrimination of tone bursts with middle intensity presented either alone or before (after) noise masker was poorer than the discrimination of the bursts with low or high intensity. We have offered a general explanation of the discrimination of the bursts presented in the different conditions. In simulation experiments, the properties of two complementary distributions of the spike activity of ensemble of peripheral fibres were studied. They were the distribution of the spike occurrence in time and the inter-spike interval distribution. Model input signals were single pulses, or combined sounds composed the test pulses that followed or preceded the masking pulses. The distribution peaks kept different information about the pulses or the combined sounds. The peaks were assumed to be neural bases for various subjective features. Changes in the amplitudes of either single pulse or the test or masking pulses of combined sound caused changes in the weights of the feature bases and their sensitivities to an amplitude increment. The results of our simulation and psychoacoustic experiments revealed a qualitative similarity. In particular, the amplitude (or intensity) discrimination of the masked model pulse (or real tone burst) depended on the amplitude's (or intensity's) ratio of the test and masking pulses (or bursts) but did not depend on positions and delays of the test pulse (or burst) relative to the masking pulse (or burst).

Keywords: Auditory nerve fibre, Ensemble, Distributions, Subjective features, Intensity discrimination

### 1. INTRODUCTION

Auditory intensity discrimination of a tone burst presented alone or under temporal masking conditions has been shown to reveal specific characteristics, the origin of which is not yet understood and differentially interpreted by various authors. Intensity discrimination of the single tone burst with middle intensity has been shown to be poorer than discrimination of a burst with either a low or high intensity (1-3). Intensity discrimination of a tone burst of middle intensity and presented after or before an intense noise masker was also shown to be poorer than discrimination of a burst with either low or high intensity (4-9).

Deterioration of intensity discrimination has been found in the intensity range of the tone burst, where a loudness enhancement effect was present. For listeners, tone bursts having middle intensity and presented under temporal masking can be perceived as louder than similar bursts presented in silence (8, 10-12). The loudness enhancement was suggested to cause an increase in the variability of the representations of intensity; therefore, the intensity discrimination may deteriorate (8, 12).

In the present work, we have offered a general explanation of these effects.

The process of converting the receptor potentials of inner hair cells into action potentials (spikes) of auditory nerve fibres could be crucial for intensity encoding of high frequency sound. According to the volley theory (13), multiple fibres simultaneously discharge to reproduce the structure of these sounds. This multiple response could be represented in the form of complementary distributions of spike activity (14). We assumed (15) that the auditory system is able to use information from at least two complementary distributions of ensemble activity of the peripheral fibers in the loudness formation or in the intensity discrimination of high-frequency pulses, presented alone or within a combined sound. These include the distribution of the spike occurrence in time and the inter-spike interval distribution. We assumed that the peaks of the distributions could create neural bases for subjective features of the test pulse and the combined sound.

In this work, the responses of the ensemble of peripheral fibres to tone pulses were simulated, and the coding properties of the ensemble, as well as the properties of the two abovementioned distributions were evaluated. In addition, it was simulated an intensity discrimination task using the

approach (16) that allow one to compared psychophysical thresholds with the sensitivity index  $d'$  (17), calculated based on the activity of peripheral fibres.

To compare the contributions of different subjective features in pulse intensity discrimination, we evaluated the weights and the sensitivity indices  $d'$  to incremental change in amplitude for the neural bases of various features, where the weight was equal to the density of the corresponding peak of the distributions. The discrimination task simulation will allow us to formulate the goals and objectives of the psychoacoustic experiments that we can conduct. The results of psychoacoustic and simulation experiments will be qualitatively compared. The coincidence of the results can confirm the hypothesis about participation the various distributions of the ensemble activity of the peripheral fibres in intensity discrimination of tone bursts presented alone or under temporal masking.

## 2. COMPUTER SIMULATION EXPERIMENTS

### 2.1 Auditory Nerve Fibre Model

To simulate the ensemble response of the auditory nerve fibres (ANF), we applied a phenomenological model (15, 18). The ANF model includes several transformation stages of an input signal  $X(t)$ : (1) the formation of the basilar membrane response  $Y(t)$ ; (2) the formation of the receptor potential of the inner hair cell  $R(t)$ , synaptic noise  $S(t)$  and the synaptic potential of the spiral ganglion neuron  $G(t)$ ; (3) the generation of a sequence of action potentials (spikes) by the spiral ganglion neuron  $Pi$ . The receptor potential  $R(t)$  was equal the response  $Y(t)$ . Synaptic noise  $S(t)$  was modeled as a random process with a mean value and a rms deviation that were proportional to  $Y(t)$ . To reproduce the SA, the rms deviation was increased by a value  $z$ . The latter value was chosen so that the SA was less than 5 spikes per second in all ANF models in the ensemble. The integration process of  $S(t)$  completed the formation of the potential  $G(t)$ . The transformation of the synaptic potential into the sequence of spikes included comparing  $G(t)$  with a time-dependent threshold function  $H(t)$ . If  $G(t)$  exceeded  $H(t)$ , an action potential (or a spike) was generated. Each spike caused a temporal increase in the threshold. During an interval equal to the sum of the absolute and relative refractoriness periods, the threshold function  $H(t)$  decreased to reach the initial value  $H_0$ . The function  $H(t)$  had fast and slow components. To simulate the adaptation properties, their initial values of these components after spike generation were increased by the residual values of the components that existed prior to spike generation.

The parameters of the ANF model were chosen to reproduce the well-known responses of the real ANF. The characteristic frequency of the basilar membrane filter in the ANF model was 4 kHz. Nonlinear properties of the BM filter were not considered because we focused on the transformation peculiarities of the receptor potentials of the inner hair cells into the spike response of the ANF ensemble. The test and masking pulses were segments of a sinusoid with durations of 5-15 ms and frequency equal to 4 kHz. The delays between the onsets of the test and masking pulses were equal to 20 - 90 ms. The calculation step in the ANF model was equal to 1  $\mu$ s.

A post-stimulus time histogram (PSTH) and inter-spike interval histogram (ISIH) were calculated based on the ensemble reaction consisting of 100 ANF models. The ensemble reaction was obtained in response to one presentation of the test pulse or the combined sound. The bin width in histograms was equal to 0.1 ms. The aggregation periods were equal to 100  $\mu$ s for PSTH and 100 ms for ISIH.

The PSTH and the ISIH obtained in response to the single test pulse had one peak. The density of the PSTH peak could be the basis for a loudness component called 'the basic loudness component,' and the density of the ISIH peak - the basis for 'the complementary loudness component' (15). The PSTH and the ISIH obtained in response to the combined sound had a pair of peaks. The PSTH peaks preserved information about the amplitudes and the relative positions of the test and masking pulses. They were responsible for the basic loudness components of the test and masking pulses. The ISIH peaks did not carry information about the temporal position of the tone pulse relative to the masker. The first ISIH peak corresponded to those inter-spike intervals whose width did not exceed the duration of the test and masking pulses. The peak combined the intervals generated in response to the test and masking pulses and constituted the complementary loudness component of the combined sound. The second peak of the ISIH corresponded to the inter-spike intervals whose width correlated with the delay of the tone pulse relative to the masker. A temporal position and density of the peak were responsible for periodicity pitch and strength of the periodicity pitch of the combined sound.

The test pulse presented alone had basic and complementary loudness components. The test pulse presented before (after) masking pulses had two basic loudness components of the test and masking pulses, as well as the complementary loudness component of the combined sound. To compare the

participation of these components in intensity discrimination task, we calculated the weights (equated to the peak densities) and sensitivity indices  $d'$  in accordance with the ratios from (19).

## 2.2 Responses of the ensemble of the fibre models to a single tone pulse

The complementary PSTH and ISIH were obtained in response to a single pulse with duration of 10 or 90 ms (Figure 1, a, b). The pulse detection threshold evaluated based on the PSTH was  $PS$  and the threshold evaluated based on the ISIH was  $PI$  (Figure 1, IY). Considering the thresholds  $PS$  and  $PI$ , the amplitudes of the pulse with a duration of 10 ms could be divided into three groups (Figure 1, a). The first group included low-amplitudes  $S$  that were lower than the threshold  $PI$ . The sum of spikes ( $N_S$ ) obtained in response to pulse presentation was lower than the number of fibres in the ensemble ( $N_S \ll 100$ ). The sum of intervals ( $MaxI$ ) was equal to zero. Each fibre could respond not more than once, and the pulse was coded by the number of excited fibres. Pulse coding scheme was stochastic. The second group included middle-amplitudes  $S$ . They were higher than the threshold  $PI$  ( $S > PI$ ). Most fibres in the ensemble were involved in the response to the pulse ( $N_S \leq 100$ ), but the sum of intervals was lower than the number of fibres in the ensemble ( $0 < MaxI < 100$ ). The fibres responded to the pulse more than once, and pulse was coded by the number of excited fibres and the number of generated spikes. The coding scheme was mixed, i.e., stochastic and deterministic. The third group included high-amplitudes  $S$ . They were significantly higher than the threshold  $PI$  ( $S \gg PI$ ). The sum of spikes ( $N_S$ ) exceeded the number of fibres in the ensemble ( $N_S > 100$ ). The pulse was coded by the number of generated spikes, and the coding scheme was predominantly deterministic.

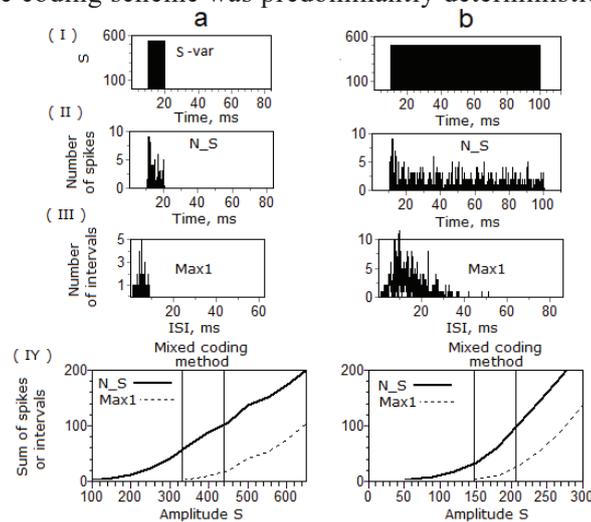


Figure 1 - Profiles of tone pulses (I), the post-stimulus histograms (II), the inter-spike interval histograms (III), the dependences of the sums of spikes  $N_S$  and inter-spike intervals  $MaxI$  corresponded to the histogram peaks on the pulse amplitude  $S$  (IV). The duration of the pulse is equal 10 ms (a) or 90 ms (b). The graphs show the amplitude of the pulse  $S$  (I), the sum of spikes  $N_S$  (II) or inter-spike intervals  $MaxI$  (III). On IV, it is marked the range of the mixed coding scheme. Abscissa: time in ms (I, II), inter-spike interval in ms, ISI, (III), the pulse amplitude,  $S$ , (IV). Ordinate: the pulse amplitudes (I); number of spikes in bin (II); number of inter-spike intervals in bin (III); sum of spikes  $N_S$  and inter-spike intervals  $MaxI$  (IV).

The division of the amplitudes into groups was related to the pulse duration (Figure 1). For pulses with a duration of 90 ms, the thresholds  $PS$  and  $PI$  were lower than that for a pulse with a duration of 10 ms, i.e., 50 and 150 ms vs 100 and 320 ms. An increase in duration caused both a reduction in the range in which the mixed coding schemes operated and a shift in the range towards the low amplitudes. Regarding this, the thresholds of  $PS$  and  $PI$  for long-duration tones would be similar and coding scheme was predominantly deterministic. However, the coding scheme of clicks was stochastic ( $PI = \infty$ ) and the complementary loudness component was absent.

To estimate participation of these components in intensity discrimination, we calculated the dependences of  $d'(N_S)$  and  $d'(MaxI)$  on  $dS$  (Figure 2). There are two horizontal lines on the graph, where  $d'$  is equal 1 or 3, i.e., the detection probability of  $dS$  was 76% and 98.5% (19). The pulse duration was 10 ms. The pulse amplitude  $S_0$  was low, middle and high. Because of significant fluctuations, the indices were calculated 10 times and averaged. The 90% confidence intervals of the mean values of  $d'$  are shown on Figure 2.

For low-amplitude pulses  $S_0$  (250), the coding scheme was stochastic, and the complementary

component was absent (Figure 2). The weight of the basic component characterized pulse loudness, and only this component contributed to amplitude discriminations of the pulses. For high-amplitude pulses  $S_0$  (750), the coding scheme was predominantly deterministic, so the two loudness components were present. They had different weights but the relative difference in their weights had decreased. The mean values of  $d'(N\_S)$  and  $d'(Max1)$  were similar, and the confidence intervals were the lowest. Both components equally contributed to loudness assessment and amplitude discrimination of the pulse.

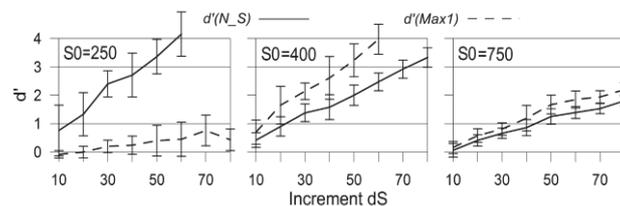


Figure 2 - The dependences of the sensitivity indices  $d'(N\_S)$  and  $d'(Max1)$  on the amplitude increment  $dS$ . The pulse amplitudes  $S_0$  are shown on graphs. Abscissa - increment  $dS$ . Ordinate - value of  $d'(N\_S)$  and  $d'(Max1)$ . Horizontal lines pass through the points  $d'=1$  and 3.

For middle-amplitude pulses  $S_0$  (400), the coding scheme of the pulses was mixed, and the two loudness components were present. In contrast to the basic component, the complementary one had a lower weight, was more sensitive to the amplitude increment, and had wider ranging confidence intervals for the mean values of  $d'$ . Feedback between the weights and the sensitivity indices  $d'$  could lower the accuracy of loudness assessment and impair the amplitude discrimination of the pulses. Thus, changes in the coding schemes could affect loudness formation and amplitude discrimination of the pulses.

### 2.3 Responses of the ensemble of the fibre models to the combined sound

The response of the ANF ensemble was received to a single presentation of the combined sound composed of the test pulse (stimulus) and the masker pulse (masker) with durations of 10 ms (Figure 3). The stimulus amplitudes  $S$  were middle and the masker amplitudes  $M$  varied from 100 to 800.

The profiles of the PSTH and the ISIH had pairs of peaks ( $N\_S, N\_M$  and  $Max1, Max2$ ). Variations in amplitude  $M$  influenced the reactions induced by the stimulus. The density of the peak  $N\_S$  changed only when the stimulus followed the masker. The densities of the peaks  $Max1$  and  $Max2$  depended on the ratio of the amplitudes  $M$  and  $S$  but not on the position and the delay of the stimulus relative to the masker or on their durations. If  $M < S$ , then the density of the peak  $Max1$  was held approximately constant, and the density of the peak  $Max2$  increased with increasing amplitude  $M$ . If  $M > S$ , then, conversely, the density of the peak  $Max1$  increased, and the density of the peak  $Max2$  remained constant with increasing amplitude  $M$ .

The three loudness components ( $N\_S, N\_M$  and  $Max1$ ) were involved in the intensity discrimination task.  $N\_S$  and  $N\_M$  were the bases for the basic loudness components of the stimulus and masker and  $Max1$  was the basis for the complementary component of the combined sound. To evaluate participation of the three loudness components in amplitude increment detection, it was compared their weights (that equate to the peak densities) and sensitivity indices  $d'$  (Figure 4). The stimulus amplitude  $S_0$  was always considered middle, equal to 400. The masker amplitude  $M$  could be low, middle or high. The weights of the  $N\_M, N\_S$  and  $Max1$  components fluctuated very weakly but the indices of  $d'(N\_S)$  and  $d'(Max1)$  fluctuated strongly. Thus, the indices were calculated 10 times and averaged. The 90% confidence intervals of the mean values of  $d'$  are shown on Figure 4.

For low-amplitude  $M$  (250) and  $S > M$ , the masker coding scheme was stochastic, and the stimulus coding scheme was mixed. The complementary component ( $Max1$ ) was formed only by the inter-spike intervals caused by the stimulus. The  $N\_M$  component did not affect increment detection  $dS$ . The weight of the stimulus basic loudness component ( $N\_S$ ) significantly exceeded the low weight of the complementary loudness component ( $Max1$ ), but sensitivities of the stimulus basic component ( $N\_S$ ) exceeded the sensitivities of the complementary component ( $Max1$ ). Thus, the feedback between the weights and sensitivities of the  $N\_S$  and  $Max1$  components could reduce the accuracy of loudness assessment and impair amplitude discrimination of the pulses. We could see the same conditions when the stimulus was presented in silence.

For high-amplitude  $M$  (750) and  $S \ll M$ , the weight of the masker basic component ( $N\_M$ ) had noticeably exceeded the weight of the stimulus basic component ( $N\_S$ ). Due to the large contribution

of the  $N_M$ , the sensitivity index of  $d'(Max1)$  decreased relative to the index of  $d'(N_S)$ . The weight of the stimulus basic component ( $N_S$ ) was low, and the sensitivity index  $d'(N_S)$  was high. By contrast, the weight of the complementary component ( $Max1$ ) was high, and the sensitivity index  $d'(Max1)$  was low. Thus, the feedback between the weights and sensitivities of the  $N_S$  and  $Max1$  components could lower the accuracy of loudness assessment and impair amplitude discrimination of the pulses.

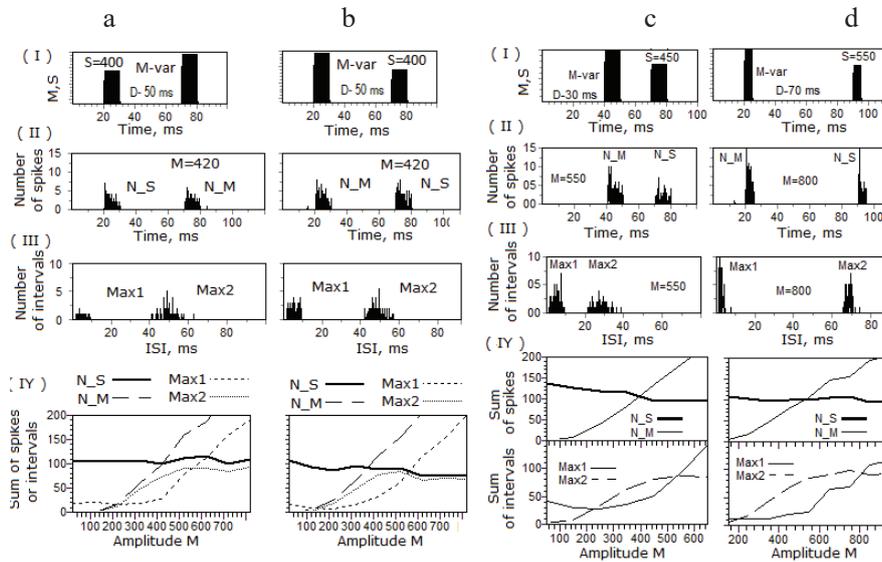


Figure 3 - Profiles of the combined sounds (I); the post-stimulus histograms (II) and inter-spike interval histograms (III); dependences of the sums of spikes ( $N_S$  and  $N_M$ ) and the sum of inter-spike intervals ( $Max1$  and  $Max2$ ) correspondent to peaks of the histograms on the masker amplitude  $M$  (IV). The graphs show the pulse and masker amplitudes ( $S$  and  $M$ ); the delays,  $D$ ; the sum of spikes  $N_S$  and  $N_M$  (II) corresponded to the two peaks of the of post-stimulus histogram arisen by pulse and masker; the sum of inter-spike intervals  $Max1$  and  $Max1$  corresponded to the two peaks of inter-spike interval histogram arisen by combined sound. On a and b, it is shown comparison of the responses to the combined sounds with different positions the pulses relative to the maskers; on b and c – with different delays  $D$  of the pulses relative to the maskers; on c and d – with different delays  $D$ , the amplitudes  $S$  and the pulse durations. Abscissa: time in ms (I, II), inter-spike interval, ISI, in ms (III), amplitude  $M$  (IV). Ordinate: the pulse and masker amplitudes (I); number of spikes in bin (II); number of inter-spike intervals in bin (III); sum of spikes or inter-spike intervals corresponded to histogram peaks (IV).

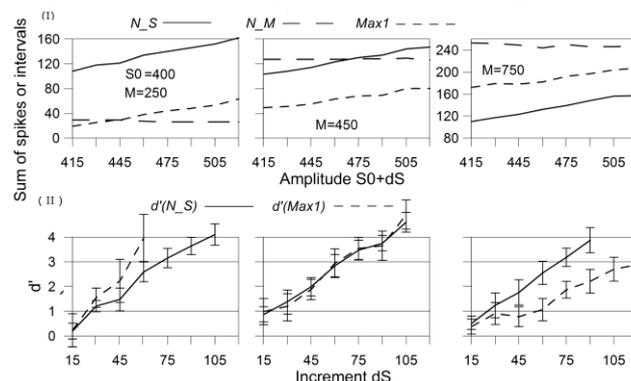


Figure 4 - The dependences of the sums of spikes  $N_S$ ,  $N_M$  and inter-spike intervals  $Max1$  on the amplitude of pulse  $S$  (I) and the dependences of the sensitivity indices  $d'(N_S)$  and  $d'(Max1)$  on the increment  $dS$  (II). The tone pulses preceded the pulse maskers. On (I), the graphs show the pulse  $S_0$  and masker  $M$  amplitudes.  $N_S$  and  $N_M$  - the sum of spikes corresponded to the two peaks of post-stimulus histogram arisen by pulse and masker;  $Max1$  and  $Max1$  - the sum of inter-spike intervals corresponded to the two peaks of inter-spike interval histogram arisen by combined sound. Abscissa: amplitude of the pulse ( $S_0 + dS$ ) (I); - increment  $dS$  (II). Ordinate: the sums of spikes ( $N_S$  and  $N_M$ ) or inter-spike intervals ( $Max1$ ) corresponded to the peaks of the two histograms (I); the mean values of indices  $d'(N_S)$  and  $d'(Max1)$ . Horizontal lines pass through points  $d'=1$  and 3.

For the middle-amplitude  $M$  (400) and  $S \sim M$ , the coding schemes of the stimulus and the masker

were mixed. The complementary component (*MaxI*) was formed by the stimulus and the masker. The weights of all loudness components (*N\_M*, *N\_S* and *MaxI*) were comparable. The complementary component (*MaxI*) could enhance one of the two basic components (*N\_S* or *N\_M*). The indices  $d'(MaxI)$  and  $d'(N_S)$  were equal. The similarity between the coding schemes, between the weights of the three loudness components (*N\_M*, *N\_S* and *MaxI*) and the indices  $d'(MaxI)$  and  $d'(N_S)$  could lead to errors in loudness assessment of the stimulus and the masker, as well as to deterioration in amplitude discrimination of the stimulus. We received a similar result when the stimulus followed the masker (it is not shown). The worst conditions for loudness formation of the test and masking pulses and for amplitude discrimination of the test pulse occurred when the pulses had middle amplitudes and their coding schemes were mixed. It is important that the amplitudes the test and masking pulses, but not their temporal positions or delays (Figures 3-4) were responsible for the coding schemes and the appearance of the complementary component of the combined sound.

### 3. PSYCHOACOUSTIC EXPERIMENTS

#### 3.1 Introduction

According to the simulation, loudness assessment and amplitude discrimination of the test pulses that followed or preceded the masking pulse depended on the ratio of amplitudes of the test pulse and the masking pulse rather than the positions and delays of the test pulse relative to the masking pulse. If similar properties we could find in the auditory perception, it would indicate that the two distributions of ANF ensemble activity involved in the pulse intensity discrimination.

The auditory deterioration of intensity discrimination and loudness enhancement of the test tone burst (stimuli) with intensity of 25-, 55- or 85-dB SPL were found when the intensity of the masking pulses was varied (9). The stimuli followed the maskers. The delay between them was 100 ms. The profiles of the dependence of the Weber fraction (or the ratio of the smallest noticeable intensity increment,  $dI$ , to the pulse intensity,  $I_s$ ;  $dI/I_s$  in dB) on masker intensity were related to the ratio of the intensity of the stimuli and maskers. If the masker intensity was lower than stimulus intensity, the values of the Weber fraction fluctuated relative to that obtained in quiet. If masker intensity exceeded stimulus intensity by less than 15-30 dB, the Weber fraction increased proportionally to the increase in masker intensity. If masker intensity exceeded stimuli intensity by more than 15-30 dB, then the growth of the Weber fraction exhibited a slowdown. For the same listeners, Oberfeld (9) estimated the loudness of stimuli that followed the masker. A significant correlation between the deterioration of intensity discrimination and loudness enhancement of the stimuli was demonstrated. Suggest that the reason for the correlation was the similarity between the stimuli and maskers. Considering data from (8, 9, 12), we designed our experiments. We aimed to obtain the dependences of the Weber fraction on masker intensity when the tone burst both followed and preceded the masking burst, the timing of the tone burst relative to the masking burst, tone burst intensity and duration varied.

#### 3.2. Method and Results

The auditory experiments were carried out in a soundproof chamber. An adaptive two-interval procedure with two alternative forced-choices was used. The test sequence consisted of two intervals. One interval contained the test and the masking bursts, and the other - the standard and masking bursts. The intervals were generated digitally as files. The files were played in a random order using the EMU 0204 24-bit audio adapter with a sampling frequency of 44.1 kHz. The sounds were presented to listeners' right ear using Shennheiser HD-265 headphones. All bursts were Gaussian-shaped sinusoids with a frequency of 4 kHz and a bandwidth of 460 Hz in the first and second series of measurements and 200 Hz in the last one. The intensities of the standard tone bursts ( $I_s$ ) were equal to 20, 30, or 40 dB SL i.e., over the individual absolute threshold for the tone burst. The intensities of the masking bursts ( $I_m$ ) varied in the range of 10-70 dB SL. The tone bursts presented before or after the masking bursts. The delays,  $D$ , between the middle parts of the tone bursts and the masking bursts were equal to 20-180 ms. Three listeners with normal hearing under the age of 35 years participated in the experiment.

The Weber fraction function was the dependence of the intensity discrimination threshold ( $dI/I_s$ ) on the intensity of the masking bursts ( $I_m$ ). For all tested listeners, the functions obtained were very similar and, therefore, were averaged. In the first series of experiments the standard tone bursts had different intensities ( $I_s$ ) and a delay ( $D$ ) of 50 ms (Figure 5, a). In the following experiment the standard tone bursts had an intensity of 40 dB SL and the delays of 20, 50 and 80 ms (Figure 5, b). In the last series of experiments, the bandwidth of the stimuli and the maskers was reduced to 200 Hz and

the range of masking intensity was increased. The tone burst intensity was equal to 40 dB SL, and the delays to 80, 130 and 180 ms (Figure 5, c). All Weber fraction functions had an inflection point that corresponded to the masker intensity being equal to the standard burst intensity. If the intensity of the masker was below the inflection point, then the Weber fraction corresponded to those obtained in quiet. If the masker intensity exceeded the inflection point, the Weber fraction increased proportionally to the masker intensity. As the intensity of the standard burst increased, the values of the Weber fraction obtained in quiet decreased. The inflection point moved towards the higher intensities of the masker. In the masker intensity range of 60-70 dB SL, the Weber fractions could exhibit a slowdown in growth. The well-known and our Weber fraction functions matched each other. The profiles of the functions depended on the ratio of amplitudes of the stimuli and maskers rather than their temporal positions and delays.

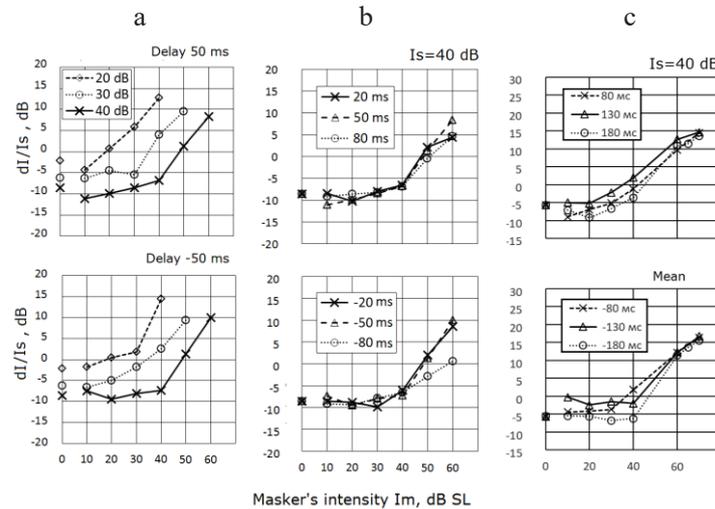


Figure 5 - The dependence of intensity discrimination thresholds for tone bursts that preceded or followed the masking bursts on the intensity of the latter. The delay has a minus sign if the stimuli preceded the maskers and a plus sign if the stimuli followed the maskers. On a and b: the bandwidth of both the stimulus and masker is equal to 460 Hz; on c – 200 Hz. Parameters on a: the intensity of standard burst; the delay between the burst and the masker; on b and c: intensity of standard burst and delays. The points on the ordinates correspond to the intensity discrimination thresholds in quiet. Abscissa: the masker's intensity in dB SL. Ordinate: intensity discrimination thresholds in dB.

#### 4. SUMMARY AND CONCLUSIONS

To explain the intensity discrimination of tone bursts presented alone and under temporal masking it was evaluated the coding schemes for high-frequency pulses with different amplitudes and durations in an ensemble of peripheral fibers. It was received the two complementary distributions of the ensemble activities received in response to the single pulse presented alone or under temporal masking. The distributions peaks carried different information about the test and masking pulses. The peaks could create the bases for the basic loudness components for the two pulses and the complementary loudness component of the combined sound.

It was found that the coding properties (Figure 3) and the amplitude discrimination properties (Figure 4) of the test pulse presented before or after masking pulse depended on the amplitude's ratio of these pulses but did not depend on their positions and delays between them. The own auditory experiments (Figure 5) confirmed this conclusions. Considering the simulation results, the intensity discrimination of tone bursts could be explained as follows:

1. The deterioration of intensity discrimination of a single mid-intensity tone bursts (1-3) could appear due to feedback between the weights and the sensitivities of the basic and complementary loudness components (Figure 1-2). The feedback could lower the accuracy of the loudness estimate and therefore degrade the amplitude discrimination of the single tone bursts.

2. The mid-intensity tone bursts under temporal masking could be subjectively louder than bursts presented alone (8, 10-12) because the complementary loudness component of the combined sound could enhance the loudness of the masked bursts (Figure 3).

3. The deterioration of intensity discrimination of the tone bursts under temporal masking (9) provided that the test and masking bursts have similar intensities could be due to the similarity of the coding schemes of the test and masking bursts and appearances the complementary loudness

component of the combined sound. The simulation revealed a relationship between loudness and discrimination of the intensity of the test pulse (6, 8, 9, and 12). In particular, for test and masking pulses with similar amplitudes (but the masker amplitude was some higher), the two loudness components were similar sensitive to the test pulse amplitude changes and the third loudness component was insensitive to that changes (Figure 4). The weight of the basic loudness component of the test pulse was less than the weight of the basic component of the masking pulse, but was more than the weight of the complementary one. The last component could enhance the loudness of either test or masking pulse. We believed that confusion in the weights and sensitivities of the three loudness components could cause deterioration in discrimination of the intensity of the test pulse. The greater the amplitude of the masking pulse, the greater the weight of the complementary component, the greater the confusion. However, if differences between amplitudes of the test and masking pulses were significant then their loudness differed better in the presence the complementary component of the combined sound (Figure 4). The feedback between the weights and the sensitivities of the basic loudness component for the test pulse and the complementary one for the combined sound could lower the accuracy of the loudness estimate and therefore somewhat degrade the amplitude discrimination of the test pulse. In this case, the causes of deterioration were similar to those that occurred in the amplitude discrimination of single mid-amplitude pulses.

Thus, our study confirmed the hypothesis (14) that the neural temporal code used by the auditory system to analysis the high-frequency sound could combine information from the complementary distributions of the ensemble activity of the peripheral fibres.

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