3pAB6. An auditory perception of changes in the intensity of pulses, presented in complicated sound complex

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The auditory system of humans and animals is able to detect and discriminate high frequency pulses in a sound complicated complex. The purpose of the work was to find new examples of facilitation the discrimination of intensity (or level, defined by a peak amplitude) of pulses, presented under composite masking conditions, and to find the possible mechanisms underlying the facilitation. The discrimination tended to deteriorate if the test pulse was presented via 50 ms after a pulse masker. However, if the pulse was mixed with additional noise masker, the beginning of which coincided with the end of the pulse masker, discrimination became better. The noise masker levels, at which facilitation occurred, depended on amplitudes of both the pulses and the pulse maskers. When the duration of the noise masker was less than 50 ms, an auditory adaptation could not influence on the discrimination. The reason of the facilitation could be in the temporal redistribution of the auditory nerve fibers activities, which occurred at coding of the temporal envelope of the sound complex "pulse masker - pulse - additional noise masker".

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INTRODUCTION

Facilitation the auditory discrimination of changes in the levels (defined by the pulse’s peak amplitude) of short high-frequency pulses, presented in noise, was discovered a long time ago (Avakyan, Radionova, 1962; Raab, Taub, 1969; Carlyon, Moore, 1984). In the auditory experiments, subjects have been compared a test pulse with a standard pulse. A threshold difference between the levels of these pulses was higher for standard pulses of average levels than low or high levels. Case of simultaneous addition of the pulses of the average levels with the noise maskers, the threshold difference decreased (Raab, Taub, 1969; Carlyon, Moore, 1984; Van Schijndel et al., 1999; Baer et al., 1999; Nizami et al., 2001, Rimskaya-Korsakova, 2007), i.e. noise facilitates the discrimination of changes in the levels of the pulses.

There are several hypotheses to explain the effects of facilitation. Our hypothesis was advanced on the basis of simulation of the encoding of the high-frequency pulses by a group of the auditory nerve fibers (ANF). (Rimskaya-Korsakova et al. 2003, Rimskaya-Korsakova, 2005, 2007). We believed that the basis for facilitation the discrimination was an adaptation of ANF.

The level of short, high-frequency pulses encodes a number of excited ANF (Young, 2007). For mid-level pulses, which correspond to area of the compressive nonlinearity of the basilar membrane, the number of ANF varies slightly (Cooper, 2004). If we assume that, in the absence of the masker all fibers were excited and involved in the on-set response, induced by pulse, the number of loose fibers that should encode the changes in levels of the mid-level pulses is practically equal to zero. This peripheral encoding should impair auditory perception of changes in the levels of pulses. However, if the pulses are mixed with prolonged noise, the noise could cause an adaptation (or change sensitivity) of ANF. Due to adaptation the threshold of the fiber shifted to higher levels of the pulses. Therefore mid-level pulses were on the threshold of ANF, on-responses were reduced or de-synchronized, and number of exited ANF decreased, while the number of unexcited fibers, suitable for coding changes in the levels of pulses, increased. After the adaptation, response of group of ANF was able to reproduce (to encode) the amplitude-temporal structure and amplitude variation (levels) of pulses. Noise improved encoding pulses, bringing them closer to the threshold of ANF. Therefore, to display the facilitation, for each level of the mid-level pulse need to find a certain level of noise.

To check the results of simulation studies, it was conducted special auditory experiments (Rimskaya-Korsakova, 2007, 2009, 2011). In case of simultaneous presentation of pulses and noise maskers with center frequencies of 4 kHz and a delay between beginning of masker and pulse of 500 ms, it was found facilitation the discrimination of changes in the levels of the pulses, which reached 6-12 dB (Rimskaya-Korsakova, 2007). For each level of the pulses (in the range of 20-40 dB above the threshold of hearing) it was found a certain level of noise at which facilitation appeared. Pulse levels were near the detection threshold in noise. According to subject's reports, during the measurements they compared test pulses with standard ones.

Later, the hypothesis about participation the adaptation in the discrimination was tested in case of sequential presentation of the same masker and pulse (Rimskaya-Korsakova, 2009, 2011). In the experiment we measured and compared discrimination and detection thresholds of the pulses. Level of standard pulse was always equal to 20 dB above the threshold of hearing. Pulse delay relative to the end of noise masker was 3, 12, 50, or 60 ms. In the presence of short masker (duration of masker less than 0.1 s) it was detected only the deterioration of discrimination compared to discrimination in silence. Facilitation of 7-12 dB appeared in the presence of prolonged masker (duration of masker 0.3-0.9 s) and standard pulse, having the level of masking of 10-15 dB. The results indicate the involvement of the adaptation.

However, if the delay between the end of the masker and pulse was 50 or 60 ms, then together with the first facilitation area near the detection thresholds pulse in the noise, we found another facilitation area (Rimskaya-Korsakova, 2009, 2011). Facilitation reached 5-9 dB and occurs at low masker levels at which the level of masking of the standard pulses was less than 5 dB. According to subject’s reports, the discrimination of the test and standard pulses in this area was improved by listening the pulses within a sound complex "prolonged masker - pulse", i.e. subjects compared sounds like "Shhhhh ... - chic" and "Shhhhh ... - snip", i.e. subjects compared changes in temporal envelopes of the sound complex.

Given the results of our earlier simulation experiments (Rimskaya-Korsakova, 2009, 2011; Rimskaya-Korsakova, Dubrovsky, 1996; Dubrovskii, Rimskaya-Korsakova, 1997, 1998), we considered that the deterioration of discrimination of pulses imposed after short masker caused the periodicity or additional low-frequency component, which arises after encoding of the sound complex by the same group of high-frequency ANF which encoded the pulse.
Short masker not adapts ANF. Reaction of ANF contains on-set responses, which coincide with the beginnings of the masker and pulse. Obtained for the group of ANF histogram interspike intervals (HISI) has a narrow peak. This peak corresponds to an interval equal to the delay between the masker and pulse. The excitation of the majority of ANF with the same delay could excite specialized neurons of direct auditory pathway configured to allocate low-frequency components (or amplitude modulation) (Frisina, 2001). In case of delay between the masker and pulse of 50-60 ms, the specialized neurons could detect the presence of low-frequency component of 20-16 Hz. Recognizing pulses, subjects compared sound complex with the same delay. If all the available number of fibers involved in the on-set responses, the same low-frequency component may deteriorate the discrimination of the pulses.

To ensure that the component is not dominant, but it helps to discriminate the pulse by analyzing changes in the temporal envelope of sound complex "masker - pulse", it should be expanded HISI and reduce its maximum, corresponding to the delay. We could do it if we de-synchronize pulse induced on-set response due to either an adaptation of ANF or a redistribution of activity of ANF. Adaptation could be caused by prolonged masker (Rimskaya-Korsakova, 2011). Redistribution could be caused by additional noise masker which mixed with pulse. We believed that the wide HISI of group of ANF with a maximum, which falls on the interval equal the delay, can improve the analysis of changes in auditory temporal envelope of the sound complexes "masker - pulse", and thus to improve the discrimination changes in the levels of the pulses.

The subsequent rise in the level of prolonged masker or additional noise masker have to move maximum of HISI into smaller interspikes interval and have to again make narrower HISI. So, we expect deterioration the peripheral coding and central analysis of the temporal envelope of the sound complex "masker - pulse." In this work, it was decided to find experimental evidence for this hypothesis. To do this, we measured thresholds of the discrimination of changes in the levels of the pulses, presented through 50 ms after the pulse's masker. The pulses were mixed with additional noise masker, the beginning of which was dated to the end of the pulse's masker. If our hypothesis is correct, i.e., if the auditory analysis of the temporal envelopes of the sound complex "complicated masker-pulse" really helps to detect the pulses within the complex, dependence of discrimination thresholds on level of the additional noise masker must have a local minimum. The level, at which there is a local minimum, should depend on the level of the standard pulses and short maskers. In addition, levels of the standard pulses must be noticeable above the pulse detection threshold under masking.

PROCEDURE

Temporal profiles of standard pulses and complicated maskers used in two series of experiments are schematically shown in FIGURE 1. The center frequencies of the comparable pulses, pulse masker and additional noise masker were 4 kHz. The width of the frequency band of additional noise masker was 600 Hz, and its duration was 115 ms. At the beginning and the end the masker had linear growth and recession parts with duration of 5 ms. The pulses and pulse masker had Gaussian envelope and sine-wave-form filling.

![FIGURE 1](image_url)

**FIGURE 1.** Schematic representation of the temporal profiles of standard pulses and complicated masker used in two series of experiments.

Bandwidth of the pulses and pulse’s masker was equal to 460 Hz; it matches the equivalent rectangular bandwidth (ERB) of the auditory filter (Moore, Glasberg, 1984). This minimizes the involvement of the spectral properties of the pulses and sound complexes in discrimination of the pulses.

Stimuli were presented via the right ear. To determine the levels of the noise masker, pulse masker and the recognizable (standard and test) pulses, it was used the value of the standard deviation of noise or peak amplitude of pulse. All values were later compared with the amplitude of a pure tone of 4 kHz, defined in dB SPL.

Levels of standard pulses were equal 20, 30 and 40 dB. Levels of pulse masker could be equal to the level of standard pulses, i.e. 20, 30 and 40 dB, or be greater than the levels of standard pulses, i.e. 30, 50 and 60 dB. Levels were determined in dB relative to individual threshold of hearing. To do this, for each subject it was measured
threshold of hearing for the pulses and noise masker in dB SPL. Discrimination threshold was estimated as the ratio of $20 \log (dA/A)$, where $A$ - peak amplitude of the standard pulse $dA$ - the minimum detectable increment of amplitude of the pulse.

Three female subjects with normal hearing have participated in measurements. The age of one subject was 58 years (Sub1), and the other two - less 30 years (Sub2 and Sub3). All subjects participated in measurements earlier.

To measure the threshold it was used an adaptive two-interval, two-alternative method of forced choice, "two-down, one-up". Subjects listened to two audio intervals with duration of 320 ms separated by 500 ms. The pulse and noise makers, as well as the test or standard pulse appeared through 200, 205 and 250 ms after the start of the interval, respectively. The threshold was equal the average of the amplitude, which was determined in the last eight from the eleven turning points.

RESULTS

Results of the measurements obtained in three subjects are shown in FIGURE 2 and 3. The standard pulses had supra-threshold levels at all levels of the additional noise masker.

In the first series of measurements the pulse masker and standard pulse had similar levels (FIGURE 2). Changes in the discrimination thresholds with increasing levels of the additional noise masker were similar in the two (Sub1 and Sub2) subjects. The curves showed minima. The greater the level of the pulse masker and standard pulse, the greater the levels of the additional noise masker, at which the minima appeared.

A value of facilitation the discrimination one could define as a difference between the discrimination thresholds, obtained in minima and in silence. The facilitation value reached 4 - 11 dB. In some cases, the discrimination threshold in the minima is less than the discrimination threshold in silence.

The data obtained for subject Sub3 were different from those obtained for other subjects. The discrimination threshold of the pulses in the presence of the pulse masker, but absence of additional noise masker was smaller for subject Sub3. The additional noise masker with low level induced an increase in the discrimination thresholds. However, the subsequent increase in the level of the noise masker caused a slight decrease in the discrimination threshold, but not facilitation the discrimination. Thus, in the presence of the pulse masker only for two of three subjects the noise masker caused some facilitation.

In the next series of measurements (FIGURE 3) levels of the pulse masker were higher by 10-20 dB than levels of the standard pulses. In this case, the growth levels of the additional noise masker caused similar changes in the discrimination thresholds for all three subjects (Sub1, Sub2 and Sub3).

For three subjects, all curves of the discrimination of the pulses had minimum. The masker noise level, at which there was a minimum, depended on the levels of the pulse masker and standard pulse. In the presence of the pulse masker, the least facilitation the discrimination was 1 dB, while the most facilitation was more than 20 dB.

FIGURE 2. Obtained for three subjects dependences the discrimination threshold of the changes in the levels of pulses on the level of the additional noise masker. Schematic illustration of the sound complex is presented in FIGURE 1.1. Parameters are the levels of the pulse masker and standard pulses in dB above the threshold of hearing. On abscissa: levels of the additional noise masker in dB, on ordinate – discrimination thresholds in dB.
FIGURE 3. Obtained for three subjects dependences the changes in the levels of pulses on the level of the additional noise masker. Schematic illustration of the sound complex is presented in FIGURE 1.2. The rest see on FIGURE 2.

From a comparison of Figure 2, 3, it follows that increasing the level of the pulse masker reduces individual differences in the discrimination curves.

Thus, we have experimental evidence that peripheral coding time envelopes of the sound complex "complicated masker - pulse", indeed, involved in the discrimination of changes in the levels of pulses.

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REFERENCES


