ELECTRICAL ACTIVITY OF THE EXTRINSIC MUSCLES OF THE HUMAN EAR AT REST AND DURING IDENTIFICATION OF ACOUSTIC STIMULI

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The electromyogram (EMG) of the human auricular muscles was investigated. A "listening" response was discovered during the identification of acoustic stimuli and consisted of activation of the EMG of the superior auricular and inhibition of the EMG of the posterior auricular muscle. The magnitude of the response bears a definite relationship to the difficulty of identification of the stimuli (the percentage of errors).

The study of specialized neuromuscular structures serving the sense organs of animals and man (for example, the oculomotor system and the motor system of the external and middle ear) is of interest both to neuromuscular physiology and also to the physiology of sensation [4, 8, 10]. Recording the activity of some of these systems, of which the oculomotor has received the most detailed study, is widely used also for experimental purposes and in medical practice for assessing responses to optical and vestibular stimulation [2, 3, 5, 6, 9]. There is experimental evidence [1, 11, 12] that the motor system of the ear can also be used as an indicator of responses to acoustic stimuli (in particular, in man for various practical investigations). However, the physiology of the motor systems of the ear in general and of the human ear in particular has been inadequately studied.

For the reasons given above and in connection with practical problems, it was decided to investigate the general characteristics of the electrical activity of the accessible part of the motor system of the ear, namely its extrinsic muscles, at rest and during the identification of acoustic stimuli.*

EXPERIMENTAL METHOD

Observations were made on 15 healthy subjects. A block diagram of the experimental apparatus is given in Fig. 1. Electromyograms (EMGs) of the superior and posterior auricular muscles were recorded by a bipolar technique with skin electrodes 4 mm in diameter. Two channels of the UBNK-V amplifier and 2 channels of the EI-2M integrator (with preamplifiers) were used. The EMGs and the marks of the integrator were recorded on a type N-102 loop oscillograph. Acoustic stimuli were taken from magnetic tape and applied to the subject through telephones and waveguides with wide Porolon earpieces. The stimuli consisted of pairs of pulses, the first of which was the reference pulse (2000 Hz) and the second the pulse for comparison, which could differ from the first by ± 40 Hz or could be equal to it in filling frequency. The distance between the stimuli in the pair was 25 msec, the duration of the stimuli 50 msec, and their intensity about 20-30 dB above zero. The pairs of stimuli were applied every 8 sec. The subject was required to distinguish qualitatively the pitch of the second stimulus relative to the first. He indicated his solution to the problem by pressing on one of three knobs ("higher," "lower," "equal"). After each pair of stimuli and the response to them the subject was told of the correct solution to this particular acoustic problem by

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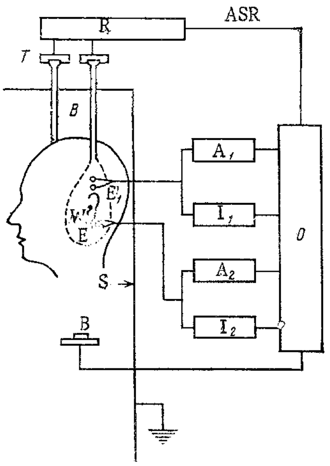

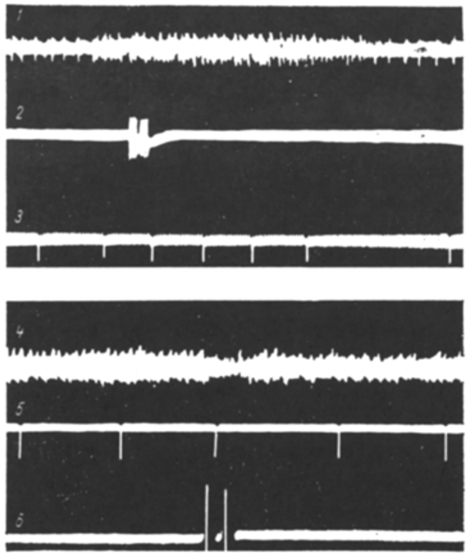

Fig. 1 Fig. 2

Fig. 1. Block diagram of the experimental apparatus. S) Screening chamber; $E_{1,2}$) recording electrodes; W) waveguide earpieces; T) telephones; R) tape recorder; ASR) acoustic stimulus recorder; O) N-102 oscillograph; B) button; $A_{1,2}$) amplifiers (channels of UBNK-V amplifier); $I_{1,2}$) integrators (channels of EI-2M integrator).

Fig. 2. EMGs of human superior and posterior auricular muscles. Response to acoustic stimuli: 1, 4) EMGs of superior and posterior auricular muscles; 2, 6) marker of application of stimuli; 3, 5) marks of integrator of EMGs of superior and posterior auricular muscles, respectively.

a recording from the tape. The analysis of the experimental results included visual analysis of the EMG and quantitative assessment of the integrator indices using a specially prepared algorithm with time storage of values representing the background and the response of the muscles to the stimuli.* A Promin'-M computer was used for the statistical analysis. The bioelectrical indices (expressiveness of the responses, degree of spontaneous activity) were compared with the correctness of identification for each pair of stimuli and for the experiment as a whole.

EXPERIMENTAL RESULTS

The investigation showed that the EMG of the superior and posterior auricular muscles recorded by skin electrodes from the human subject is a typical interference EMG in which biphasic waves of potential predominate. The mean amplitude in spontaneous activity was 30–50 μV. The frequency of the waves during spontaneous activity was variative with a mean value of 100/sec.

Visual analysis of the EMGs showed that at the times when the subjects received the acoustic stimuli there was a clear change in amplitude of the EMGs of the extrinsic muscles of the ear: an increase (activation effect) in the superior auricular muscle and a decrease (inhibition of the EMG) in the posterior auricular muscle (Fig. 2). The response of the EMG of the posterior auricular muscle described above was more distinct and constant.

The changes described above in the electrical activity of the auricular muscles were distinctly reflected in the dynamics of the integrator indices when the time accumulation method was used (Fig. 3). The integrator indices showed that the combined response of the extrinsic muscles of the ear began in 64% of cases after the stimuli and had a short (less than 0.2 sec) latent period, and in 36% of cases it began 0.3–1.5 sec before the stimuli. Similar effects of a response preceding the stimuli when applied in a regular rhythm have been described in the literature [3] and assessed as a manifestation of a conditioned reflex to

*The accumulation interval was 200 msec.

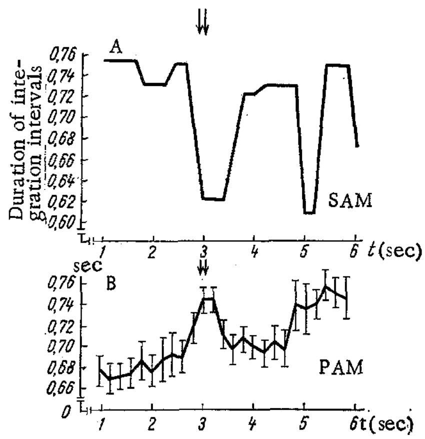

Fig. 3. Characteristics of responses of human superior (A) and posterior (B) auricular muscles as reflected by integrator readings: A) curve of response to one pair of stimuli; B) average curve for 23 responses in another experiment. Vertical lines show confidence intervals (for B). Moments of application of stimuli (pairs of acoustic stimuli) indicated by arrows. Responses in part of record of this experiment given begin before stimulus and continue during and after its action.

time. The duration of the electrical response of the test muscles was 1.1-1.6 sec. Sometimes immediately after the direct response to the stimuli a second response was observed, for which special analysis was required; this is outside the scope of the present investigation.

In their form and temporal course the changes in electrical activity of the human extrinsic muscles of the ear described above correspond to the orienting reflexes of alerting the ears in animals [7]. These responses of the extrinsic muscles of the ear to acoustic stimuli in man evidently have no essential functional role (the intrinsic muscles of the ear function effectively). Nevertheless, the responses of the human extrinsic ear muscles can be regarded as symptoms of listening.

Because of the weakness of responses of the extrinsic muscles of the ear it was difficult to compare the magnitude of each of these responses with the correctness of the subject's answer to the stimuli applied. For this reason all that was done was to estimate the ratio between the averaged indices for the experiment and for a group of similar experiments.

Comparison of the magnitude of the averaged response of the extrinsic muscles of the ear with the mean percentage of mistakes in experiments lasting 30 min showed positive correlation ($r = 0.87$) between them, or in other words, under those conditions a higher percentage of mistakes in identification of the acoustic stimuli corresponded to greater expressiveness of the listening responses. This can be understood to mean that the listening responses appear or become strengthened in the subjects when identification of stimuli becomes difficult for them. In this case the responses of the extrinsic muscles of the ear thus play the role of an indicator of the operator's difficulty in solving acoustic problems.

The dynamics of the ratio between the expressiveness of responses of the extrinsic ear muscles and the percentage of mistakes made by the operator was investigated in a series of prolonged experiments (the indices were averaged over 30-min intervals of the experiment). The results showed that at the beginning of the experiment positive correlation still remained between the parameters. At the end of the experiment, however, with the development of severe fatigue of the operator the percentage of mistakes rose sharply and the listening responses weakened. Probably under those conditions this particular adaptive mechanism fails.

There is reason to hope that the electromyographic responses of the extrinsic ear muscles described above will find use as an indicator of the state of the auditory system in persons whose work entails the perception of acoustic stimuli.

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