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# Estimation of the Neural Noise Within the Human Thalamus

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With 10 Figures

**Summary**

We systematically studied neural noise patterns in 18 Parkinsonian patients with the aid of an amplitude averaging circuit for quantitative estimation of the neural noise level. In our anterolateral to posteromedial tracks, the following results were obtained and discussed from practical points of view.

1. It is demonstrated that the variation of the neural noise level along the descent of the electrode corresponds well to different subcortical structures, and is therefore reliable for identifying them precisely.

2. In and around the VL nucleus, there were some differences in the neural noise pattern between the medial and lateral groups. In the medial group (4 cases), upper borders of the thalamus were clearly delineated, but lower borders were not. Steep increases of the noise level were found about + 10 mm above IC-line probably corresponding to the entrance of VL nucleus and the upper half of the VL showed the highest level. On the other hand, in the lateral group (6 cases), intrathalamic noise patterns were not so characteristic as medial group and noise levels were lower. In three cases upper borders of the thalamus were not so distinct. Lower borders were, on the contrary, more clearly distinguished than the medial group.

3. Cases with simultaneous recordings with two electrodes in parallel with frontal section were reported. This method was proved to be useful in delineating the lateral edge of the thalamus, especially in the case with dilatation of the third ventricle.

4. In the Vim nucleus, high levels of the neural noise were demonstrated. Activity of kinesthetic neurons were mostly found, if any, among the higher noise levels.

## Introduction

In stereotactic operations for such extrapyramidal manifestations as tremor, rigidity and athetosis, neurophysiological techniques as well as radiological measurement are now essential for the precise localization of the electrode tip in the depth of brain. For example, observation of the single or multiple unit discharge with a microelectrode technique has been proved to be useful in delineation of the thalamic nuclei (Albe-Fessard *et al.* 1963, Jasper and Bertrand 1966, Velasco and Molina-Negro 1973).

Using the unitary recording technique we have already reported some functional aspects of the thalamus such as activity of sensory neurons and spontaneous burst discharges (Ohye *et al.* 1972, Ohye *et al.* 1974) and their practical aspect in relation to placing therapeutic lesion (Fukamachi *et al.* 1973). From these experiences, we have noted that different sites in the brain, or even in the thalamus,

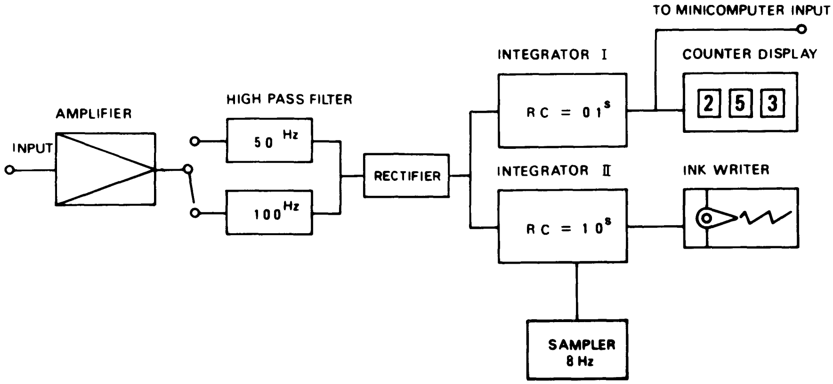


Fig. 1. Block diagram of neural noise quantification method or amplitude averaging circuit. 100 Hz—High Pass Filter is usually used. Explanation in the text

have different amplitudes of the neural noise. Here, the background neural noise is defined as a fast activity behind unitary spikes and such activity is believed to be over-all action potentials generated by cells and fibers surrounding the recording electrode. It is, therefore, conceivable that any difference in the amplitude of the neural noise denotes some anatomical difference.

Saito and Ohye (1974) developed an automatic or semiautomatic analog control device for micromanipulator motordrive. With a digital voltmeter in this system, quantitative estimation of level of the neural noise is always possible at each position during the course of insertion of the electrode. Neural noise levels thus obtained were proved to be very useful in delineating the thalamic nuclei and surrounding structure. We always use this quantitative estimation of the neural noise in addition to other electrophysiological devices for the precision in locating the target. In this paper we describe the neural noise quantification technique and a systematic study of the neural noise patterns within the human thalamus.

## Materials and Methods

The present report is based upon observations made during stereotactic operations in 18 cases with Parkinson's disease. They were operated awake under local anesthesia with premedication of 10 mg of chlorpromazine. Operative targets were the ventralis lateralis (VL), ventralis intermedius (Vim) nuclei or sub-VL, Vim areas.

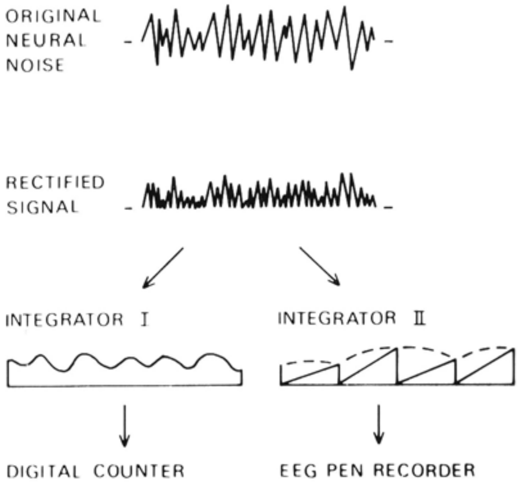


Fig. 2. Schematic figure for measurement of the neural noise level

The principal methods of the extracellular recording in the depth of brain were almost the same as those described in our previous papers (Ohye *et al.* 1972, Ohye and Narabayashi 1972, Fukamachi *et al.* 1973, Ohye *et al.* 1974). Briefly, an Insl-X coated bipolar concentric steel electrode (outer diameter: 0.6 mm, tip: 10–20 μm, resistance: 50–60 kΩ, distance between two poles: 0.5–1 mm) was introduced in an anterolateral to posteromedial direction through a frontal burr hole. As an analog control device was prepared for micromanipulator motordrive (Saito and Ohye 1974), the electrode was advanced at first by a rough manipulator in millimeter step and secondly, in the thalamus, especially in the ventral part, by an automatic micromanipulator in micron step. Bipolar recording between the two poles was usually made. In the majority only one needle track was used in each case. In two cases simultaneous recordings were made with two electrodes in parallel with frontal section, using a millimeter step manipulation. Frontal, pre- and post-central and occipital scalp EEGs were recorded throughout the whole operative procedure to monitor the patient's general cerebral activity. Surface bipolar electromyogram of the contralateral limb was also recorded on the cathode ray oscilloscope or pen-writing oscillograph. When sensory responses were obtained, touch, pressure or joint movement were signalled with a small strain gauge attached to the appropriate area.

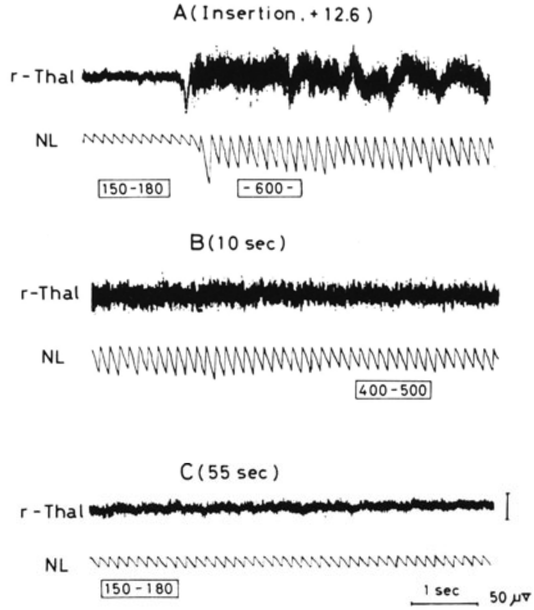


Fig. 3. An example of time sequential changes of transient mechanical injury discharge due to insertion of the electrode. Recording point is 12.6 mm above IC-line. A) Just at the insertion. B) 10 seconds after. C) 55 seconds after. Saw-tooth waves and numbers in squares indicate averaged neural noise levels. *Thal* thalamus, *NL* neural noise level

## *Recording and Measurement of the Neural Noise*

In the case of deep-brain recording, suitably amplified with a high-gain amplifier, the neural activity was displayed on a cathode ray oscilloscope and photographed on a running film. If necessary, it was recorded on a jet-writer (Mingograf) during the course of insertion of the electrode. At the same time, it was also recorded on FM magnetic tape for later analysis and monitored on a loud speaker for facilitating the procedure.

Measurement of level of the neural noise was made through an averaging circuit as shown in Fig. 1. Output from the amplifier was led to a highpass filter with cut-off frequencies of 50 and 100 Hz. This filter was used to eliminate slow wave activity and pass only spikes to the next stage. These spikes were then rectified by a full-wave rectifier and the amplitude of rectified activity was half of the original neural noise. Rectified signal was further introduced

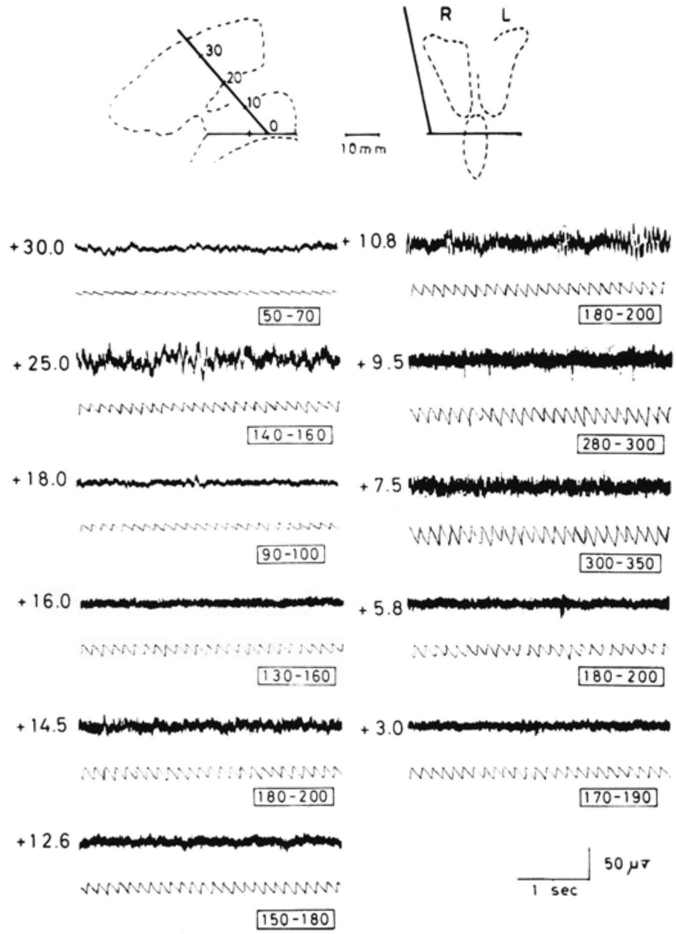


Fig. 4. Demonstration of recording and measurement of the neural noise in various depth of the brain in a 59-year-old woman with Parkinson's disease. Numbers indicate the distance in millimeters from IC-line. Upper two figures show the direction of the track projected to the shadow of the third ventricle in its lateral (left) and anteroposterior (right) views after pneumoventriculography. The inter-commissural distance was 26 mm and the maximum width of the third ventricle was 6 mm as measured on X-ray. Saw-tooth waves and numbers in squares indicate averaged neural noise levels

into two kinds of integrator. Through integrator I with a short time constant (RC = 0.1 second), level of averaged amplitude of the neural noise was continuously displayed by a digital voltmeter. The number of two or three figures displayed on the counter indicates the value of about five times ($\times$ 10 ÷ 2) of averaged original noise amplitude in microvolts. When 253 is read as a level of neural noise, it denotes about 50 μV as an averaged amplitude of the original

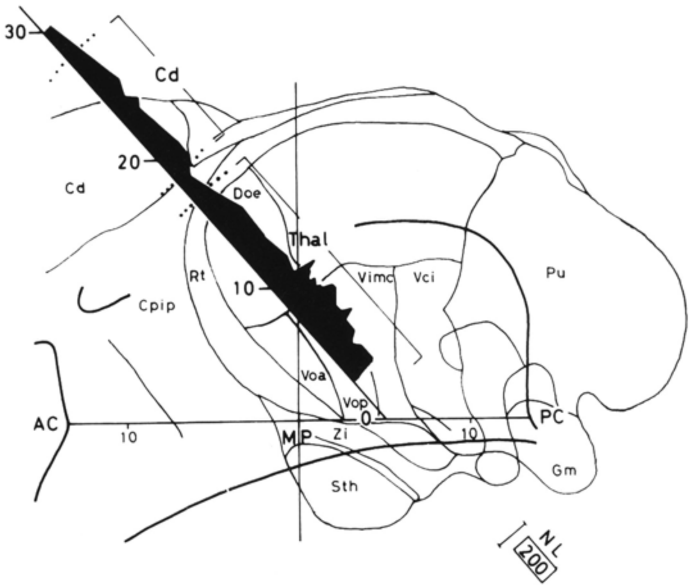


Fig. 5. Neural noise pattern of the case in Fig. 4 with a reproduction from Schaltenbrand and Bailey's atlas (S. 1. 13.5) and a lateral view of the third ventricle. Dotted lines indicate borders of the caudate nucleus (*Cd*) and thalamus (*Thal*). *AC* anterior commissure, *PC* posterior commissure, *MP* midpoint of IC-line, *NL* neural noise level

noise. On the other hand, through integrator II with a longer time constant (RC = 1 second) combined with 8 Hz-sampler, the averaged level of the neural noise was converted to amplitude of saw-tooth wave (8 Hz) and recorded on EEG pen recorder or jet-writer. Thus the level of the neural noise could be continuously read in two ways during the course of insertion of the recording needle. Fig. 2 shows a schematic drawing of the conversion mentioned above.

In general, at the time of insertion of the needle, the initial increase of the noise level due to so-called injury discharges was found (Fig. 3 A) and the level decreased gradually with the lapse of time (Fig. 3 B). In the present analysis of thalamic neural noise, the noise level at a given point was indicated by the stable level some time (20 to 60 seconds) after the insertion. In this illustrated case the noise level at this point was regarded as 150 to 180 (Fig. 3 C).

Although unitary large spikes distinguished from the background noise were also calculated in this system, their spontaneous discharge

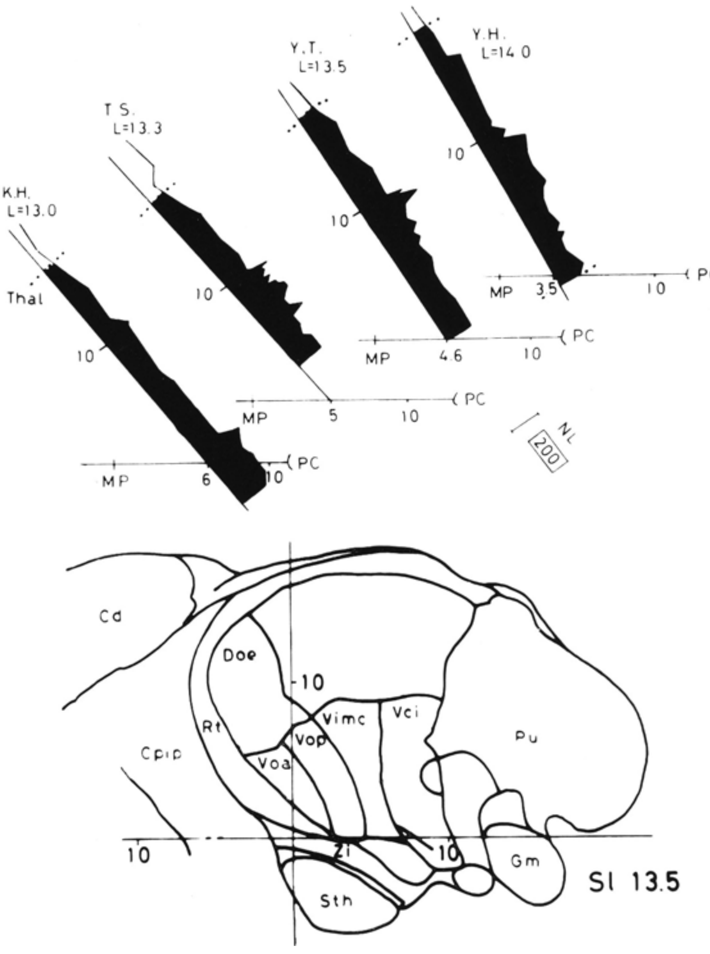


Fig. 6. Neural noise patterns in the medial group (4 cases) with a reproduction from Schaltenbrand and Bailey's atlas (S. 1. 13.5). "L = 13.0" indicates 13.0 mm lateral from midline on the level of IC-line. Dotted lines: borders of the thalamus (*Thal*). *MP* midpoint of IC-line, *PC* posterior commissure, *NL* neural noise level, numbers in millimeters

frequency was small in comparison with that of the background fast activity. The effect of unitary spikes to the noise level was therefore negligible.

## Results

### *Case Presentation*

A typical example of recording and measurement of the neural noise is shown in Fig. 4. This case was a 59-year-old woman with Parkinson's disease. Recording was made along a track penetrating toward the spot 5 mm behind the midpoint of intercommissural line (IC-line) and 13.3 mm lateral from the midline, as shown in the upper part of the figure.

In the white matter, or at a point + 30.0 mm above IC-line, level of the neural noise was 50 to 70 with frequent positive small spikes. In the caudate nucleus, or at a point + 25.0, it was around 150 with irregular wide spikes. At a point + 18.0, the level decreased again less than 100 suggesting that the needle had entered the white matter ventral to the caudate nucleus. When the tip of the electrode arrived at a point + 16.0, sudden increase of the noise level was found and this point was considered to be an upper limit of the thalamus. In the thalamus, various noise levels with some spikes or burst discharges were noticed at various points as shown in the figure. In the dorsal part of the thalamus levels of the neural noise were approximately 150 to 180. Upper half of the ventral part (+ 9.5 ~ + 7.5) revealed the highest level of the noise in the thalamus, the value being around 300. In the lower half of the ventral thalamus (+ 5.8 ~ + 3.0) a decrease of the level was found to be less than 200.

This continuous variation of the neural noise levels along its track was shown in Fig. 5, superimposed on a reproduction from Schaltenbrand and Bailey's atlas (S.1. 13.5) and a lateral view of the third ventricle. It was demonstrated that the neural noise variation corresponded well to subcortical structures and the caudate nucleus, white matter and thalamus were precisely delineated. Furthermore, in this case, ventral half of the thalamus corresponding approximately to the entrance of VL nucleus could be clearly distinguished from the dorsal one. Inferior limit of the thalamus could not be delineated in this case, because the recording needle was stopped at a point + 3.0 mm above IC-line.

As this demonstrats, variation of the neural noise levels gives us a continuous information along the descent of the electrode into subcortical structures, and therefore is reliable for identifying them precisely.

### *Different Noise Patterns Between Medial and Lateral Trackings*

In the frontal view, tracks of recording electrodes penetrate through the subcortical structures between 13 and 18 mm lateral from midline on the level of IC-line. Difference of patterns of the thalamic neural noise levels within these limits was studied in 10 cases, especially with regard to medial and lateral tracks. Posterior limits of these cases were 1 to 6 mm behind the midpoint of IC-line and no responses were obtained to peripheral natural stimuli. These 10 cases were therefore considered to be concerned mainly with the VL nucleus. For the sake of convenience, tracks of 13 to 14 mm lateral from midline on the level of IC-line were grouped as medial and tracks of 15 to 16 mm as lateral.

Fig. 6 shows the neural noise patterns of the medial group (4 cases). As shown in the case presentation, changes of the intra-thalamic neural noise were characteristic. Steep rises of the noise level were found around a point + 10 mm above IC-line and the levels of the upper half of the ventral thalamus were the highest in the thalamus. In the dorsal thalamus over + 10 mm, levels of the neural noise were 150 to 180, in the ventral upper half 200 to 300 and in the ventral lower half less than 200. In the medial group, upper limits of the thalamus were usually clearly delineated, but lower limits were not so clearly demarcated. Only one in four cases showed a marked decrease of the noise level around IC-line.

Fig. 7 shows the noise patterns of the lateral group (6 cases). Although some degree of dispersion was seen, the noise levels of the lateral group were in general lower than those of the medial one. Rises of the noise levels around + 10 mm above IC-line were not so marked as the medial group, but the higher levels were seen rather in the lower half of the ventral thalamus. Three cases (M. S., K. T., and F. I.) showed low levels of the neural noise with positive small spikes in the dorsal thalamus. In these three cases, upper limits of the thalamus were not so distinct. On the other hand, lower limits were more clearly distinguished in the lateral group than the medial one.

Fig. 8 shows two cases whose recordings were made simultaneously with two tracks in parallel with frontal section. Difference of the neural noise patterns between the medial and lateral tracks revealed the tendency described above. Especially in the case T. M., upper and lower limits of the caudate nucleus and thalamus were clearly demarcated. These simultaneous recordings revealed further the fact that the lateral and medial tracks had their respective upper and lower limits at different heights, being probably due to the anatomical shapes of the caudate nucleus and thalamus. From a practical point of view, it is important to evaluate the lateral edge of the thalamus when the dilatation of the ventricles, especially of the third ventricle, is found by radiological examination. In the case N. N., the third ventricle was 10 mm in width and dilated slightly. Neural noise levels on the lateral track penetrating a spot 18 mm

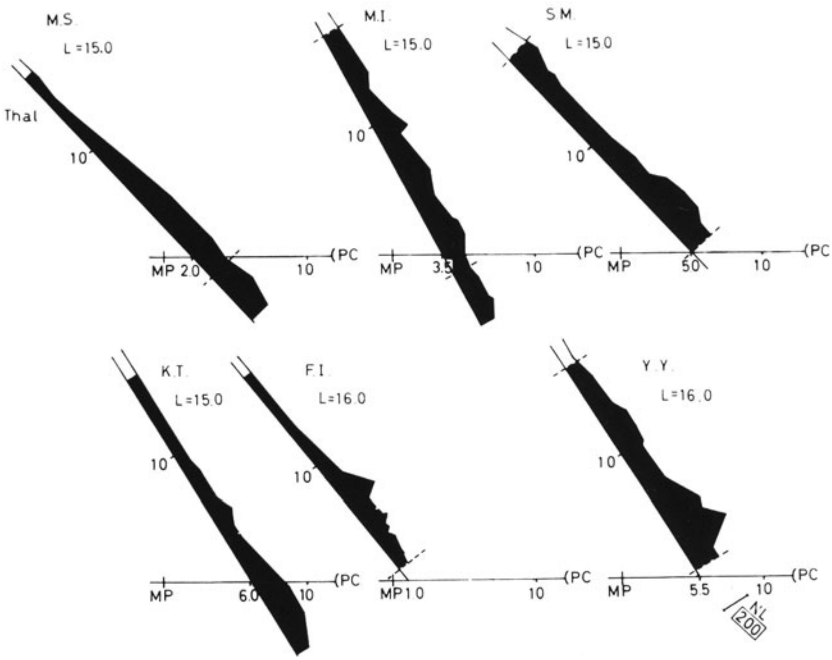


Fig. 7. Neural noise patterns in the lateral group (6 cases). Dotted lines indicate borders of the thalamus (*Thal*). *MP* midpoint of IC-line, *PC* posterior commissure, *NL* neural noise level, numbers in millimeters

lateral from midline were extremely low in comparison with the medial levels. The lateral track was therefore thought to pass through the very lateral part of the thalamus. On the other hand, in the case T. M., the lateral track penetrating a point 19 mm lateral from midline showed higher levels than the former case. It was accordingly conceivable that in the case with dilatation of the third ventricle there might be a reduction of the size of the thalamus itself.

## *Neural Noise Patterns in the Cases With Sensory Responses*

In six cases, sensory neuronal responses to peripheral natural stimuli were obtained (Fig. 9). These tracks passed through posteriorly between 7.8 and 9.8 mm behind the midpoint of IC-line and laterally between 15.0 and 17.5 mm lateral from midline. Although sensory modalities were various (joint movement, passive stretch of muscle and deep pressure), purely tactile neurons were not encountered. These sensory neurons were therefore in a region between

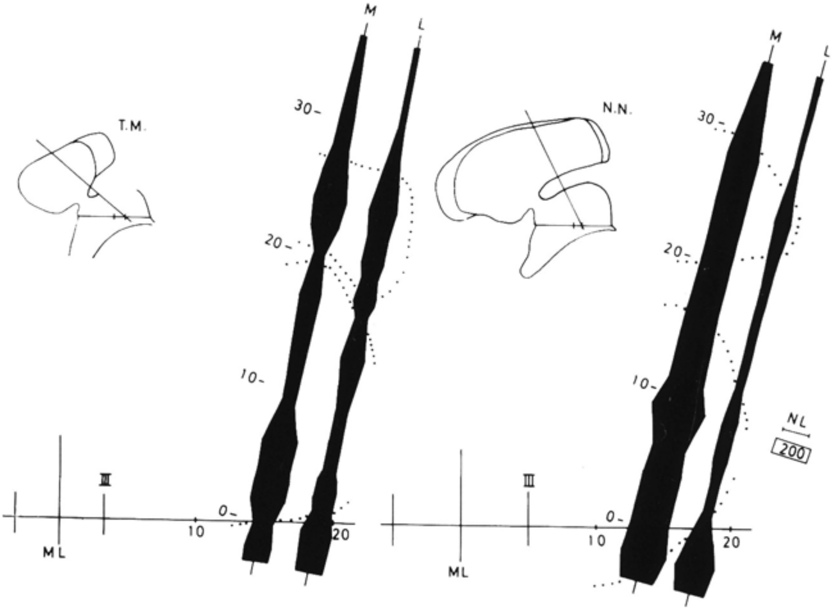


Fig. 8. An example of two cases with simultaneous recordings. In the case N.N. width of the third ventricle (III) was 10 mm and in the case T.M. 6.5 mm. Dotted lines indicate borders of the caudate and thalamus determined by changes of the neural noise. *M* medial track, *L* lateral track, *ML* midline, *NL* neural noise level, numbers in millimeters

the VL nucleus and the tactile area of the ventralis posterior. In one case (T. S.) evoked potential to peripheral nerve stimulation as that described by Goto *et al.* (1968) was obtained in this region. This region was thought to be the Vim nucleus.

Neural noise patterns in these cases were not so characteristic as the medial group mentioned above, but rather similar with the lateral group. Referring to the Schaltenbrand and Bailey's atlas, high levels of the noise were seen in the Vim nucleus. Kinesthetic neurons were mostly found among the higher background noise levels.

Difference of the noise level patterns between the VL and the Vim nucleus is not yet confirmed in individual case, but Figs. 6, 7, and 9 shows a tendency that the Vim nucleus has higher levels than the VL.

Finally one typical example of a 52-year-old male is presented in Fig. 10. Recording point is illustrated in B. Pressure on the left ankle evoked a multiunitary response in the thalamus. Neural noise was also elevated simultaneously. Digital voltmeter indicated around 300 before and over 400 just after the stimulation.

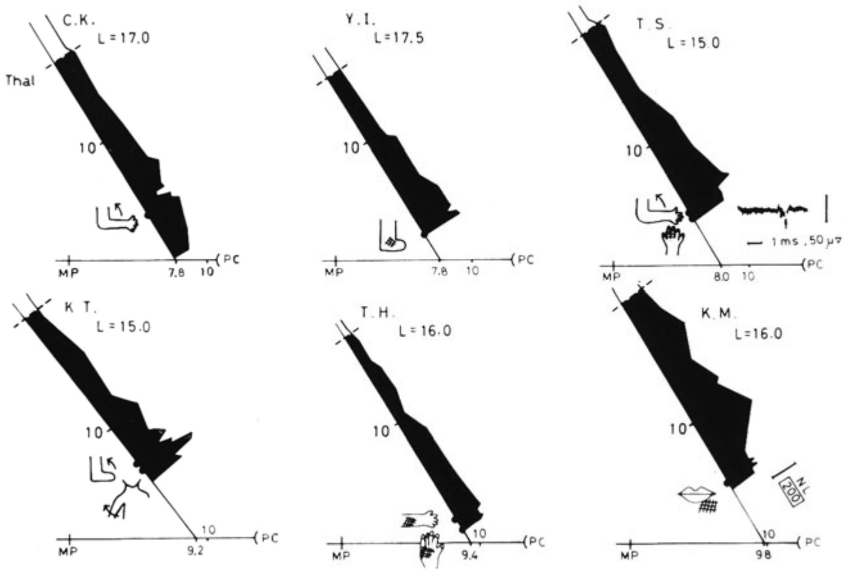


Fig. 9. Neural noise patterns in the cases with sensory responses (6 cases). Dotted lines indicate upper limits of the thalamus. Lower ones were not determined in these cases. Solid circles indicates the thalamic points of neurons with sensory responses. Schematic figures of a part of the body indicate the respective peripheral receptive field. The qualities of effective stimuli are indicated as follows: arrow; joint movement, a group of small dots; tapping, lattice; deep pressure. In the case T.S. an evoked response to median nerve stimulation is illustrated. *MP* mid-point of IC-line, *PC* posterior commissure, *NL* neural noise level

## Discussion

Neural noise, or background fast activity, is thought to be primarily action potentials generated by cells and fibers surrounding the electrode (Arduini and Pinneo 1962, Podvoll and Goodman 1967, Schlag and Balvin 1963, Weber and Buchwald 1965, Buchwald and Grover 1970). It is also reported that the background activity is high in certain regions which are found to correspond to individualized nuclei or groups of nuclei (Schlag and Balvin 1963, Buchwald and

Grover 1970). Schlag and Balvin (1963) described that it was not yet possible to state whether size or density of cells or both, or additional factors were responsible for this result. Grover and Buchwald (1970), however, studied the correlation between the local morphology and the fast activity amplitudes. Their data suggested that neither fiber projections nor cell density contribute importantly to the differential large and small amplitudes of fast activity. They

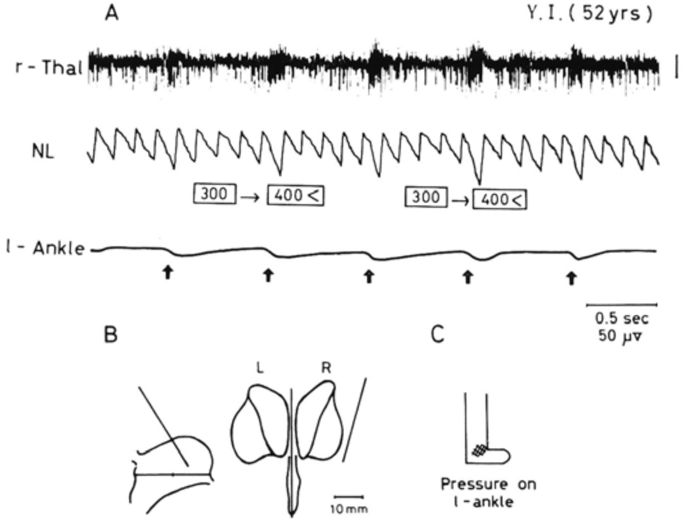


Fig. 10. An example of a case (Y.I. in Fig. 10) with sensory response. Deep pressure on left ankle was the effective stimulation (C in Figure). Thick arrows in A) indicate moments of the applied pressure. *Thal* thalamic recording, *NL* neural noise level. B) Recording point

concluded further that, in contrast, the fast activity amplitudes had shown a strong correlation with maximum cell diameter and seemed a more probable function of cell size than of the other variables. Therefore, it is conceivable that the background activity appears to be dependent upon the morphological characteristics of the cellular environment and the measurement of the activity level is valuable for localizing electrodes in the brain, as demonstrated in this paper.

Several investigators (Albe-Fessard *et al.* 1963, 1966, Hardy and Bertrand 1965, Hongell *et al.* 1973) described briefly the background activity in the human thalamus. However, there is no literature which concerned a detailed study on the neural noise patterns in the human thalamus, especially in the VL and Vim nuclei. Hongell *et al.* (1973) described that at a position 13 to 18 mm above IC-line there was an increase in spontaneous multiunit activity indicating the entry into the thalamus and at about 10 mm there was additional increase in overall activity probably indicating the entry into the VL nucleus. From our results, the medial group is similar to the description by Hongell *et al.*, but the lateral one is not. In fact, the medial group revealed the higher levels in the upper half of the VL nucleus than the lower half. In the lateral group three cases showed a very low level with frequent positive small spikes in the dorsal thalamus. That is probably due to considerably lateral penetrations of needles or existence of more abundant myelin fibers in the dorsolateral region of the thalamus (*cf.*, Dewulf's atlas, 1971). Accordingly when such low neural noise pattern is obtained, it must be considered that the electrode is penetrating through a fairly lateral part of the thalamus. In the thalamus, as far as examined by our anterolateral to posteromedial tracks, the Vim nucleus seemed to have the highest level of the neural noise. Cytometric studies by Dewulf *et al.* (1971), being the only available histological datum in the literatures, revealed that the Vim nucleus had larger macroneurons than the VL and the dorsal thalamus. This would be compatible with our results but further precise correlative study will be necessary.

In the case of the third ventricle dilatation, it is important to evaluate the size of the thalamus for determining an operative target. Assuming that atrophy of the basal ganglia can result in an increase of the width of the third ventricle (Selby 1968), placing a lesion in the same manner as in the persons with normal width may introduce such hazard as hemiparesis. Bogren *et al.* (1971) reported that the immediate result of the operation was better in patients with small than in those with wide third ventricles. As described in our results, assessment of the neural noise pattern is a good method for detecting the lateral border. Simultaneous recordings with two tracks in parallel with frontal section was proved to be more reliable in delineating the thalamus, especially its lateral edge.

Similarly the neural noise assessment was useful in distinguishing the upper and lower borders of the thalamus. Regarding the lower limit which is important for the sub-VL or sub-Vim thalamotomy, the lateral group demarcated it more clearly than the medial one, though the reason was not clear. Detail of this problem will be described separately elsewhere.

Finally, functional aspect will be discussed briefly. It is well known in animal experiments that there is a decline in the averaged multiple unit activity in the reticular and thalamic sites during the transition from wakefulness to slow-wave sleep (Podvoll and Goodman 1967, Goodman and Mann 1967). Although changes of the neural noise levels during wakefulness and sleep have not yet been reported in the human thalamus, it is likely that the similar phenomenon exists. In fact we have experienced several cases; in one case neural noise level was 180 to 200 while she was dozing, but it increased to 250 when she became more awake and tremor in the limb appeared. Neural noise patterns described in the results were therefore obtained in the stable states in regard to the patients' level of consciousness.

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