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THE EFFECT OF PERIPHERAL STIMULATION ON UNITS LOCATED IN THE THALAMIC RETICULAR NUCLEI

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Angel & Dawson (1961, 1963), showed that the electrical potentials recorded from the cortex and thalamus after the application of a brief electrical test stimulus to the periphery were increased in size if this stimulus was preceded by a strong peripheral stimulus, either pinching, rubbing or trains of electrical stimuli applied anywhere on the body surface. These responses, which were recorded from the thalamus at a site corresponding to the ventrobasal complex of Rose & Mountcastle (1952) and also from the primary receiving area of the cerebral cortex, were found to be mediated by activity conveyed in the dorsal columns. The pathway from the periphery to the cerebral cortex activated by the test stimulus will, therefore, be called the dorsal-column sensory pathway. In addition it was found that the increase in size of the thalamic response recorded from a mass of cells could be related to the behaviour of single thalamic units. A study of the responses of these single thalamic units showed that after a strong peripheral stimulus they would discharge with an increased probability and a shorter and less variable latency than in the resting state. Furthermore, these units were not discharged by the strong peripheral stimulus, unless it was applied to the same body site as the test stimulus. Through what pathways a strong peripheral stimulus applied to any part of the body surface increases the responsiveness of units in the cortex and thalamus to a subsequent test stimulus is an open question; but other units have been found elsewhere in the thalamus which are influenced by stimulation of any part of the body surface. This paper is concerned with the relation between the change in the activity of units in the thalamus outside the dorsal-column pathway, and the changes occurring in the sensory cortex and thalamus in the dorsal-column sensory pathway. A preliminary account of this work has been published elsewhere (Angel, 1961).

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METHODS

The animals were anaesthetized with either trichloroethylene or urethane, the depth of anaesthesia being adjusted so that the animal just failed to show a reflex withdrawal of the hind paw to a strong pinch. With urethane the dose required, administered as a 25 % solution in saline by intraperitoneal injection was 1·3–1·5 g/kg.

The electrodes used to record the cortical potentials were made from silver wire; one was placed on the somatic receiving area, the other was further back on the cortex. Potentials in the thalamus were recorded through glass micropipettes having a tip diameter of 2–5 μ, filled with an 18 % solution of sodium chloride and with a resistance of 2–4 MΩ. Insertion of the micro-electrode was observed microscopically and measurements of depth were made from the level just before dimpling of the cortex was observed. This coincided with a sudden reduction of 'noise' from the loudspeaker used to monitor the signals.

The micro-electrode was connected to the grid of one of a pair of cathode followers having a grid current of less than $1{\cdot}5 \times 10^{-11}$ A, the grid of the other being earthed. In some experiments artifacts caused by vascular pulsation and/or respiratory movement were reduced by attenuating all frequencies below 100 c/s by as much as 95 %; this was permissible because the shape of the potential recorded was unimportant and only the frequency of discharge of the unit was of interest. All records were made extracellularly.

Electrical stimuli were applied by means of lint pads soaked in 18 % sodium chloride solution. The negative electrode of the pair was wrapped around the wrist or ankle, and the positive one around a digit. The pressure under the electrodes was kept low. The stimuli were pulses of 100 μsec duration, having a rise time of not more than 1·5 μsec, continuously variable in size from 0 to 120 V, and isolated from earth by a one-to-one low-capacity transformer. The number and frequency of trains of stimuli were controlled from a batch counter using dekatrons and the timing of the stimuli was controlled by a digital timing unit (Pitman, 1958). Occasionally a pinch with a pair of forceps was used as a strong peripheral stimulus and it was of sufficient intensity to cause reflex withdrawal in the lightly anaesthetized animal.

The methods used for determining the site of penetration of the micro-electrode and verification of the position from which records were made have been dealt with fully in a previous paper (Angel & Dawson, 1963).

RESULTS

In 30 albino rats 124 single thalamic units which could be influenced by stimulation, both electrical and 'natural', of any part of the body surface were studied. Two types of unit could be distinguished; first, units whose frequency of discharge was increased after peripheral stimulation; secondly, units whose frequency of discharge was decreased after peripheral stimulation.

Increased frequency of discharge

This group comprised 51·5 % of the total number of units (64 out of the 124). The resting discharge of this type of unit depended upon the anaesthetic agent employed. With urethane anaesthesia this type of unit showed a wide range of resting discharge rates, from 0 to 29 imp./sec. The average frequency of resting discharge over a period of 5–10 sec was 10 imp./sec or less, 80 % of the units studied had an average frequency of resting discharge of 5 imp./sec or less. The solid line in the histogram (Fig. 1) represents the range of frequencies of resting discharge of 42 of the units of this type studied for periods of 20 min or more and from which photographic records were made.

In animals anaesthetized with trichloroethylene units of this type were found to have resting discharge rates ranging from 20 to 30 imp./sec. Two units which showed no resting discharge in two animals anaesthetized with urethane increased their rates to 23 and 28 imp./sec, 15 sec after the animals had been given trichloroethylene to breathe.

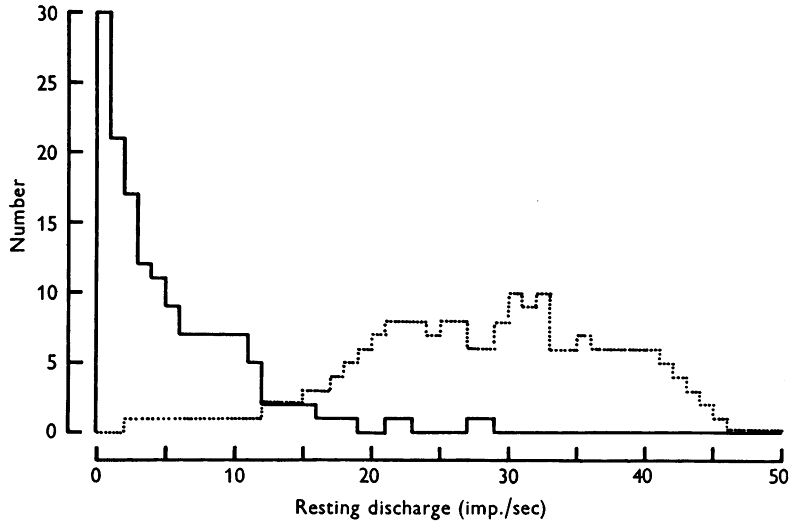

Fig. 1. Number of times a particular frequency of discharge was seen, in the resting state, against the frequency for 42 units whose frequency of discharge was increased after a strong peripheral stimulus (——) and for 24 units whose frequency of discharge was decreased after a strong peripheral stimulus (........).

The effective stimulus for producing a change in frequency of discharge of this type of unit appeared to be strong stimulation of the periphery. Weak stimuli such as tapping, moving hairs, resting light weights on the skin or rotating the joints appeared to have no effect, whereas strong stimuli such as pinching, cutting or rubbing the skin gave an immediate effect. Figure 2 shows the effect of pinching (*a*) the left hind paw and (*b*) the right hind paw on the frequency of discharge of a thalamic unit. This figure also shows that the response of the unit outlasts the application of the stimulus by 0·9 sec in (*a*) and by 1·4 sec in (*b*); and that there was a slight increase in frequency of discharge of the unit after the removal of the stimulus, seen more obviously in (*b*). The frequency of discharge of this unit could be increased by pinching the skin anywhere on the animal; in fact, no unit of this type was found which could be influenced only by stimulation of a limited part of the body surface.

Figure 3 shows the effect of applying an electrical stimulus to the periphery. The stimulus consisted of 34 electrical shocks with a separation of 3 msec and a strength 20 times that of the threshold for an evoked cortical potential. Figure 3*a* shows the records obtained from a thalamic

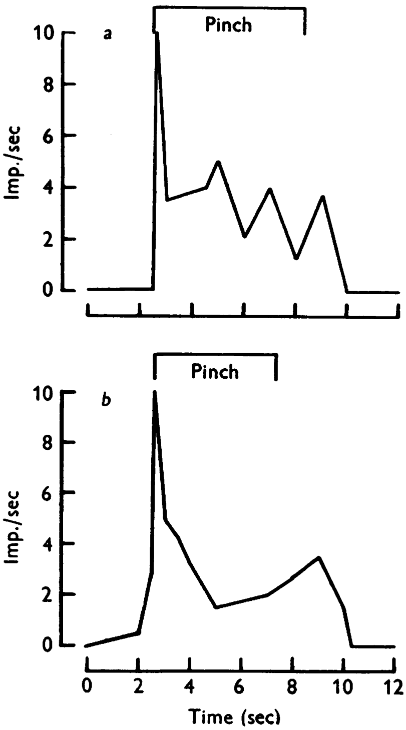

Fig. 2. Increase in frequency of discharge of the first type of unit from the left thalamus to a strong peripheral stimulus, which in this case was a hard pinch applied to the left hind paw (*a*), and to the right hind paw (*b*). The animal was anaesthetized with urethane.

unit, the resting discharge labelled *R* and four consecutive responses to the strong peripheral stimulus labelled *S*. The graph (Fig. 3*b*) is the average of ten consecutive responses. To obtain average figures each record was divided into consecutive 100 msec periods, the start of the electrical stimulation being taken as zero time, and the number of impulses occurring in each 100 msec period was then counted. The number of impulses in corresponding periods, with reference to zero time, was then summed in each of the ten responses, giving the average frequency per second for that period. The graph of Fig. 3*b* is a plot of these values and shows that the increase in frequency of discharge of the thalamic unit lasted for 2·5 sec and that the peak of the effect occurred between 500 and 600 msec after the start of the train of stimulii.

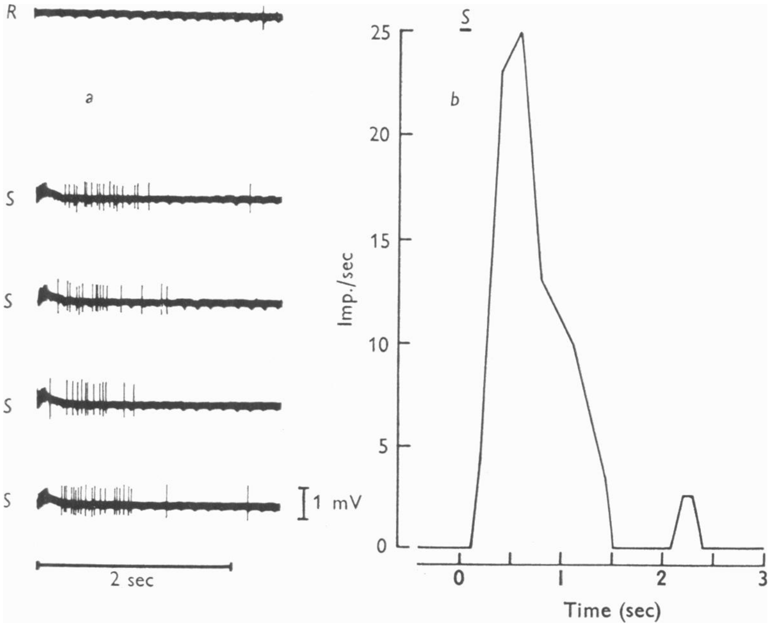

Fig. 3. *a*. The top trace (*R*) shows an extracellular record of the resting discharge of a unit in the thalamic reticular substance on the left-hand side. The other traces (*S*) are records of the responses of this unit to a train of impulses (34 shocks with an interval of 3 msec) applied to the left hind paw. *b*. Averaged response of the unit to ten such stimuli as in *a*, applied to the left hind paw. The horizontal line labelled *S* indicates the duration of the strong peripheral stimulus. In this and all subsequent figures an upward deflection signals positivity at the tip of the micro-electrode or active cortical lead.

Figure 4*a* shows the effect of electrical stimulation of the periphery when the stimulus was applied to each of the four limbs in turn. Each graph is the average of ten consecutive responses. The resting discharge of this unit varied between 0–3 imp./sec with an average frequency over 10 sec of 1 imp./sec.

Decreased frequency of discharge

Of the 124 units studied 60, i.e. 48·5 %, were found to belong to this group; and of these 60 units 1 was found whose behaviour was different from the rest. The resting discharge frequency of this group of units ranged from 2 to 46 imp./sec, with 80 % of the units having an average

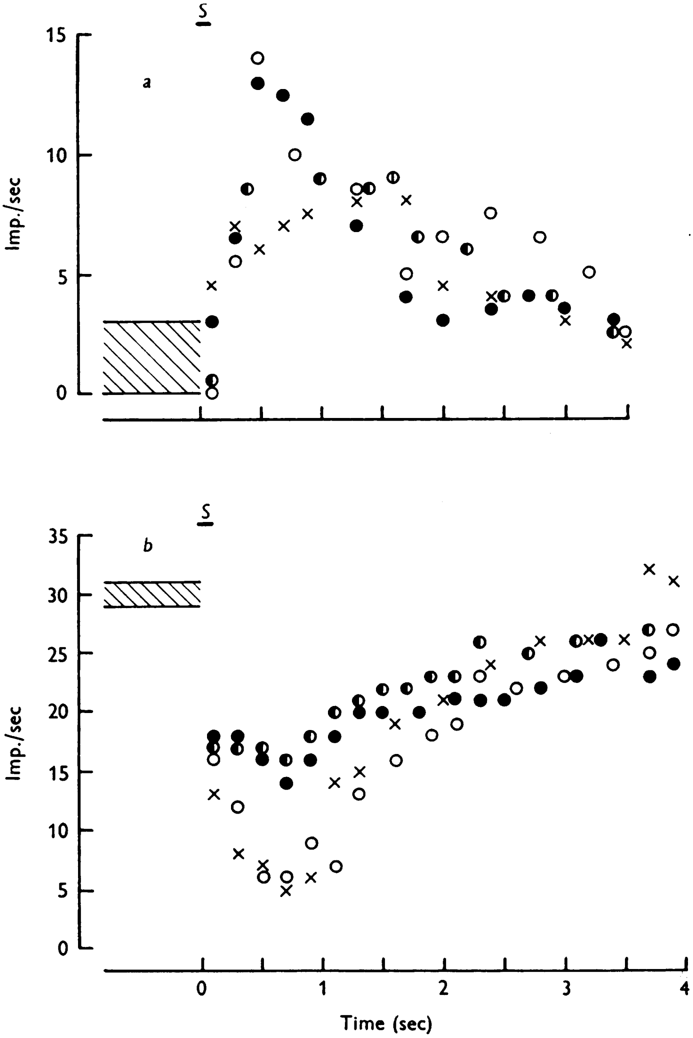

Fig. 4. Convergence of somatic stimulation on to thalamic reticular units. The response of the two types of units is shown; one whose frequency was increased by a strong peripheral stimulus (*a*), and one whose frequency was decreased after a strong peripheral stimulus (*b*). The stimulus used in all cases was a train of stimuli consisting of 34 shocks with an interval of 3 msec. The horizontal lines labelled *S* indicate the duration of stimulation. The variation in the spontaneous activity of both types of cell is indicated by the hatched area. These units were recorded from an animal anaesthetized with urethane. Site of stimulation ○, left hind leg; ×, left foreleg; ◐, right hind leg; ●, right foreleg.

frequency of resting discharge of 20 imp./sec or more (Fig. 1, dotted line histogram). The frequency of discharge of this type of unit was not affected when an animal anaesthetized with urethane was given trichloroethylene to breathe, and for similar depths of anaesthesia with the two anaesthetics the frequency of resting discharge was found to be approximately the same. If an animal which was sufficiently deeply anaesthetized to abolish reflex withdrawal was given an extra amount of urethane to bring the dose up to 1·8 g/kg it was found that the resting discharge

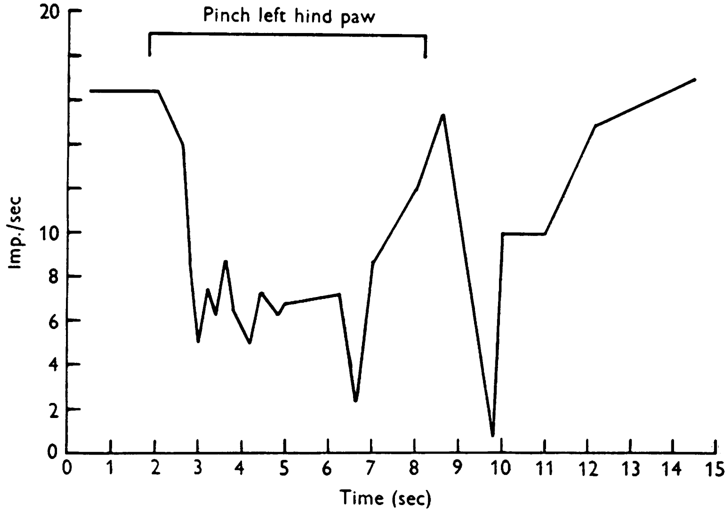

Fig. 5. The graph shows the decrease in frequency obtained with the second type of unit in response to a hard pinch of the left hind paw. The animal was anaesthetized with urethane. The frequency decreased both when the pinch was applied and when it was released.

frequency was decreased but that the range of frequencies of resting discharge was increased. For example, in one experiment the resting discharge frequency of a unit of this type in an animal anaesthetized with urethane 1·3 g/kg was from 23 to 26 imp./sec, with an average frequency of discharge of 25 imp./sec. When the dose of urethane was increased to 1·8 g/kg the resting range of frequencies of discharge was found to be from 8–22 imp./sec, with an average frequency of discharge of 12 imp./sec.

The effective stimulus to cause a change in the frequency of discharge of this type of unit was again a strong peripheral stimulus. Figure 5*a* shows the response of a unit of this type to a strong pinch applied to the left hind paw, the pinch being of a sufficient intensity to cause reflex withdrawal in the lightly anaesthetized animal. It can be seen that the effect took approximately 1 sec to develop fully, after which the frequency very nearly came back to normal, and finally that on releasing the pinch the frequency of discharge of the unit again decreased and returned to the resting value after 6 sec. Figure 4*b* shows that this type of unit can also be influenced by electrical stimuli applied anywhere on the body surface. The behaviour of a unit of this type after an electrical stimulus is shown in the records of Fig. 6*a*. These records show the resting discharge (*R*) and the response of the unit to four consecutive peripheral stimuli (*S*). The peripheral stimulus used was a train of 34 electrical impulses with a

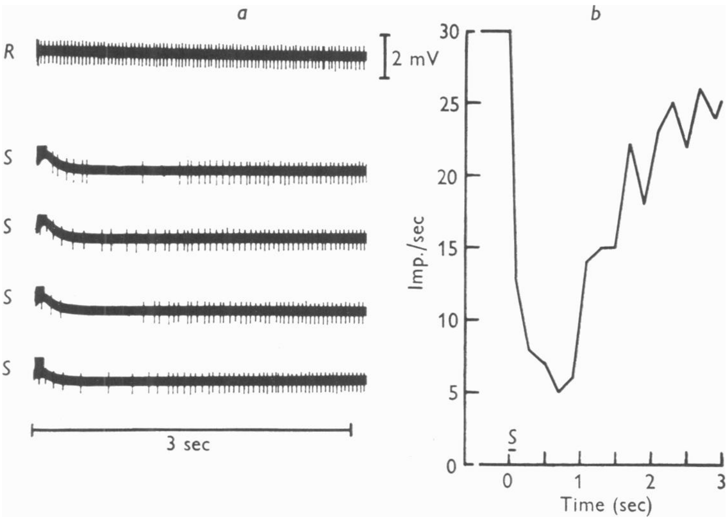

Fig. 6. *a*. The top record (*R*) shows the resting discharge of the second type of unit which can be found in the thalamic reticular substance. The other records (*S*) are the response of this unit to a strong peripheral stimulus consisting of a train of 34 shocks with a 3 msec interval. *b*. shows a graph of the frequency change of this unit to stimulation. Ten consecutive responses have been selected and the average response plotted. The duration of the stimulus is indicated by the horizontal line labelled *S*. Animal anaesthetized with urethane.

separation of 3 msec, and a strength 20 times the threshold for an evoked cortical response. The graph on the right (Fig. 6*b*) is the average response of this unit, situated in the left thalamus, to ten consecutive stimuli applied to the left hind paw. It can be seen that the peak of the effect came 500–600 msec after the start of the stimulus and that it lasted for longer than 3·0 sec. The records from the unit show that after the stimulus the return of the discharge to the resting state is relatively smooth. This is not always the case, however, as sometimes the return to the resting rhythm is preceded by a series of high-frequency bursts (Fig. 7).

One of the units of this group displayed the typical properties for a time and then suddenly started to behave differently; a strong peripheral stimulus sometimes caused complete cessation of discharge. While it was silenced it could be brought back to its normal frequency by a single strong stimulus applied to any part of the periphery.

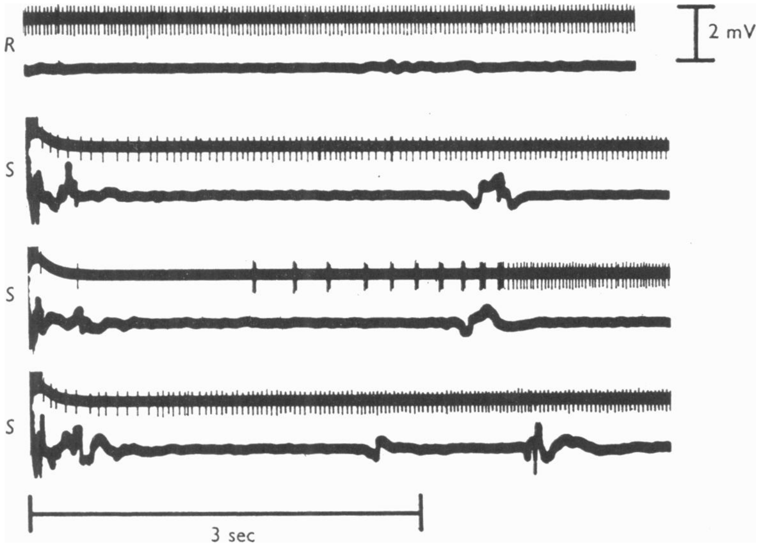

Fig. 7. The records shown were made extracellularly from a unit in the left thalamus (top trace), and from the primary somatic receiving area on the left-hand side (bottom trace). The top record (*R*) shows the resting activity. The next three records (*S*) are consecutive responses to a strong peripheral stimulus applied to the right forepaw. The middle record of the three shows the unit returning to its resting frequency in a series of high-frequency bursts. Recorded from the same animal as Fig. 6.

Relation between changes in frequency of thalamic units and changes in the dorsal-column sensory pathway

It has been noted (Angel & Dawson, 1963) that in some cases the cortical evoked potential could be increased in size after a pinch had been applied to a peripheral site, but that the effect gradually wore off, though it reappeared when the pinch was released. The same qualitative behaviour could be seen when the frequency changes of both types of thalamic unit were examined after the application of a pinch. The graphs of Figs. 2 and 5 show that the frequency was altered both when the pinch was applied and when it was released. It was found, in some experiments, that pushing the micro-electrode into and through the thalamic nuclei from which these unit discharges were recorded could cause changes in the evoked cortical response. This was particularly so when injury discharges were produced.

Angel & Dawson (1961, 1963) have shown that the potentials recorded from the ventrobasal thalamus and sensory cortex became larger after a strong peripheral stimulus. The same strong stimulus was used in the present experiments on six animals in which records were made from at least one unit of each type, and simultaneously from the primary cortical receiving area. An increase in size of the first parts of the cortical potential was found to follow a similar time course to that of the change in frequency of the thalamic unit, regardless of whether this was one in which the frequency was raised or lowered. This similarity in time course of the effect of a strong peripheral stimulus on the cortical mass response and on the thalamic unit discharge, was found both in animals anaesthetized with urethane (four experiments) and with trichloroethylene (two experiments). However, with trichloroethylene an important difference appears. The results of two experiments showing this difference are plotted in Fig. 8. The solid-line graphs show the averaged frequency responses of the thalamic units to ten consecutive strong peripheral stimuli. The interrupted lines show the average of the increase in size of the first negative wave of the cortical potential (see Fig. 1, Angel & Dawson, 1963), evoked by test stimuli applied at various times after the start of the strong peripheral stimulation. It can be seen that although the increase of the cortical response and the change in the thalamic unit (increase or decrease in frequency) run together, the over-all duration of the effect of the strong peripheral stimulus is much shorter with trichloroethylene (Fig. 8*a*) than with urethane (Fig. 8*b*).

The relation between the size of the strong peripheral stimulus and the changes in frequency of the thalamic units on the one hand, and the size of the first negative wave of the cortical potential on the other, was examined in two experiments, performed on animals anaesthetized with urethane. In these two experiments the strength of the test stimulus, and the interval between the start of the strong peripheral stimulus and the test stimulus, were kept constant; the only parameter which was varied being the intensity of the strong peripheral stimulus. It was found that the amount of change, either increase (Fig. 9*a*) or decrease (Fig. 9*b*) in the frequency of the thalamic units, was nearly proportional to the size of the strong peripheral stimulus. From these same experiments it appears that the change in size of the first negative wave of the cortical response, although it shows more scatter, is related almost linearly to the size of the strong peripheral stimulus (Fig. 9*c*). A graph of the relation between the change in size of the cortical response and the change in frequency of an excited and an inhibited thalamic unit is shown in Fig. 9*d*. From the series of graphs shown in Fig. 9 it can be seen that the relation between the discharge frequency of the thalamic units and the size of the primary components of the evoked cortical potential is almost linear.

The lines of the graphs in Fig. 9 do not pass through the origin but intersect the axis at a stimulus strength of approximately 10 V. It has been found in other experiments recording from the sural nerve, after an electrical stimulus to the hind leg, that at a stimulus strength of 10–15 V a group of fibres is excited with a maximum conduction velocity of

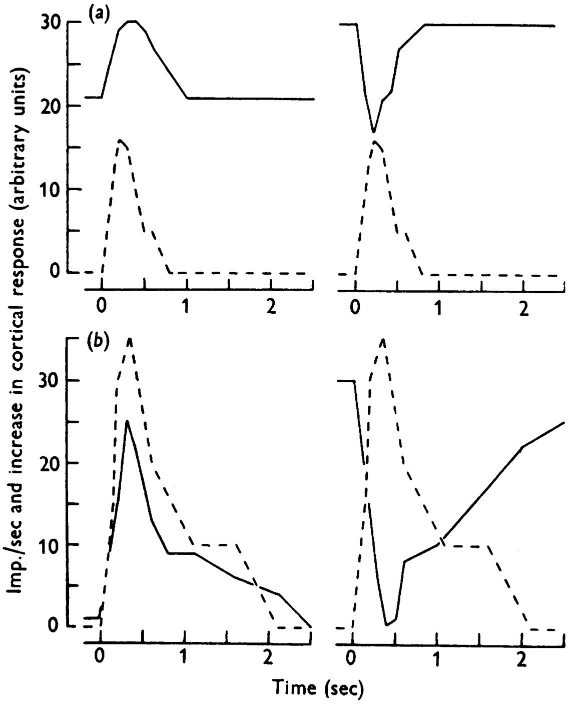

Fig. 8. This series of graphs shows the behaviour of the two types of unit found in the thalamic reticular substance in animals anaesthetized with (*a*) trichloroethylene or (*b*) urethane. A strong peripheral stimulus, consisting of 34 shocks with a separation of 3 msec, was applied to the left hind paw. The increase in size of the first negative wave of the cortical response is shown by the interrupted line, and the change in the frequency of the unit is indicated by the continuous line. The graph of the unit whose frequency was decreased (*a*) has been displaced upwards for clarity by a distance equivalent to 7 imp./sec, i.e. resting discharge plotted as 30 instead of 23 imp./sec. --, Cortical response; —, unit response.

2·3 m/sec. At this stimulus strength a faster group of fibres with a conduction velocity of 40 m/sec has nearly reached its maximum activity. It is thought, therefore, that the effect of a strong peripheral stimulus is mediated by the slowly conducting group of fibres.

It was also found that if the trains of strong peripheral stimuli were applied faster than 1/2 sec the increase in the evoked cortical response decayed, although the trains of strong peripheral stimuli were still continued. In the same way the effectiveness of the strong peripheral stimulus in changing the frequency of discharge of both types of thalamic unit fell off. This is shown, for a unit of the type whose frequency of discharge

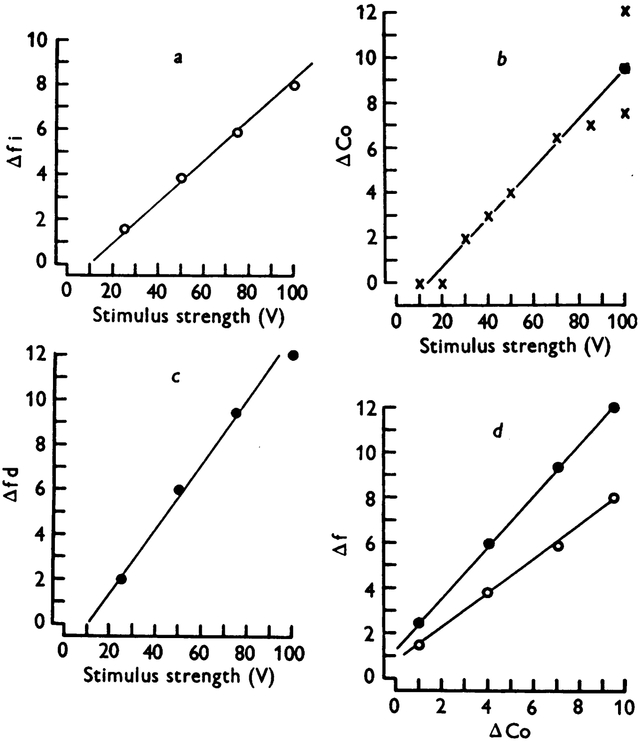

Fig. 9. The graphs show the change in frequency of discharge of both types of thalamic unit, and the change in size of the evoked cortical response (at a fixed time after the start of a strong peripheral stimulus) when the size of the strong peripheral stimulus was changed: *a*, from a thalamic unit whose frequency was increased; *b*, from a thalamic unit whose frequency was decreased; *c*, the increase of the first negative wave of the evoked cortical response (arbitrary units); *d*, the change in frequency seen at each stimulus strength versus the increase in the cortical response at that stimulus strength. The points in graphs *a* and *b* are the average of 10 observations. Those in graph *c* are the average of 20 observations. Animal anaesthetized with urethane.

was decreased after a strong peripheral stimulus, in Fig. 10. It can be seen that the discharge frequency of this unit gradually returned to the resting level although the strong peripheral stimulus was still being applied. Whether this is a peripheral or central effect is not known.

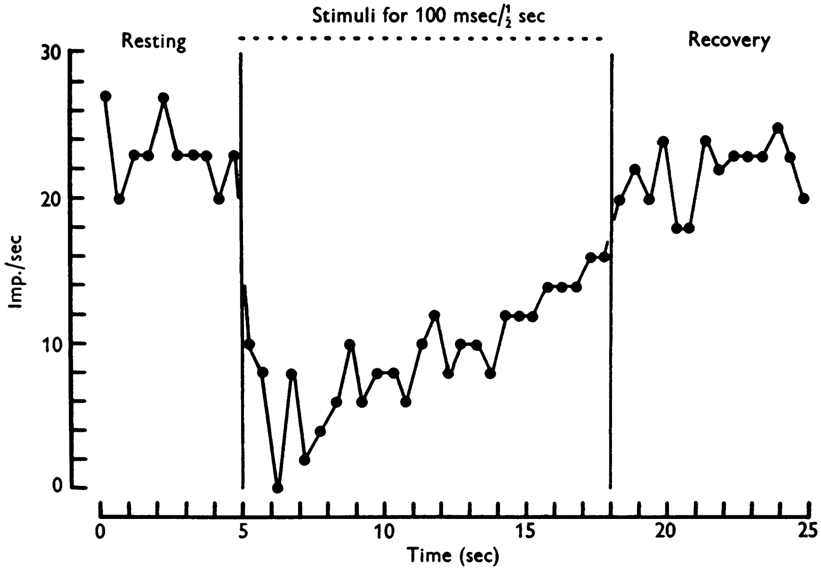

Fig. 10. The figure shows the gradual return of the frequency of discharge of a thalamic unit towards normal when the strong peripheral stimulus was applied repeatedly to the left hind paw, in an animal anaesthetized with urethane, at a rate of twice/sec. The period in which the stimuli were applied is indicated by the two vertical lines; the time of application and the duration of each stimulus by the small horizontal dashes.

Anatomical localization of the thalamic units influenced by stimuli applied anywhere on the body surface

The brains of ten animals from which records of the discharges from these types of thalamic unit had been made were examined histologically. At the end of the experiment coarse guide needles were inserted into the brain in known positions and for known depths to calculate the shrinkage. The brains were fixed *in situ*, removed, and sectioned serially in 25–50 μ sections and stained with 0·1 % thionin. The co-ordinates of the penetration and the depth below the surface at which the activity recorded being known, the position of the thalamic units could be inferred. The co-ordinates of the position of the recording electrode could be read with an accuracy of $\pm 0{\cdot}1$ mm in the antero-posterior and mediolateral axes, so that in the figure allowance has been made for this potential source of inaccuracy. The co-ordinates in the antero-posterior direction were first plotted as a histogram; the area in which 80 % of the responses were recorded was then plotted on the section; this was then repeated for the other two axes and finally Fig. 11 was drawn. In a great number of cases the unit discharge could be recorded over a large depth; in these instances the position of the unit was taken as being at the depth of penetration where the electrical potentials had the greatest voltage. In other cases the unit was taken as being at the depth at which the electrode caused the start of an injury discharge or the sudden cessation of all activity.

The section on which the positions of the nuclei have been plotted was obtained by taking the co-ordinate, from the antero-posterior histogram,

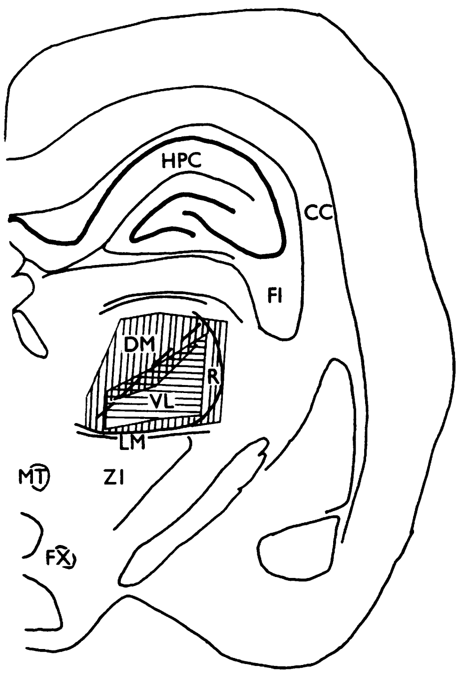

Fig. 11. This shows the anatomical distribution of the two types of thalamic unit (vertical hatching) and, for comparison, the thalamic sensory relay nucleus (horizontal hatching). CC, Corpus callosum; FI, fimbria; FX, fornix; HPC, hippocampus; LM, lemniscus medialis; MT, mammillothalamic tract; DM, nucleus ventralis thalami pars dorsomedialis; VL, nucleus ventralis thalami; ZI, zona incerta.

in which the most penetrations were made. The results of penetrations on this co-ordinate, and on co-ordinates within 0·2 mm on either side of it, were then plotted (Fig. 11). The position from which responses could be recorded after localized weak peripheral stimulation has also been plotted on this figure for comparison. There is an apparent overlap of the region in which units excited by the strong peripheral stimuli were found (Fig. 11, vertical shading) with the portion of the thalamus in which responses in the dorsal-column pathway were recorded (Fig. 11, horizontal shading). This occurs because the nuclei change their shape in the antero-posterior direction. The units influenced by stimuli applied anywhere on the body surface were found to be in the nucleus reticularis thalami and the nucleus ventralis pars dorsomedialis (Fig. 11, R and DM). The two types of unit were found in roughly the same proportions in each of these nuclei. The part of the thalamus concerned with the transmission of information to the primary receiving area of the cortex, with a short latency, is found to be the nucleus ventralis thalami (Fig. 11, VL). (The naming of these nuclei is taken from De Groot (1959); they are the same as those given to these parts of the thalamus by Gurdjian (1927), except for the naming of the last one, which he called the nuclei ventralis thalami pars ventrolateralis.)

DISCUSSION

It has been found that in animals sufficiently deeply anaesthetized to abolish reflex withdrawal there are two distinguishable types of discharge which can be recorded from the thalamic reticular substance, and in no instance has it been possible to convert one type into the other. Similar observations have been made by Moruzzi (1954), Yoshii & Ogura (1960) and Yoshii, Matsumoto & Ogura (1960) for units located in the pontile reticular formation of the cat. Scheibel, Scheibel, Mollica & Moruzzi (1955), on the other hand, found that a fixed type of stimulus might increase or decrease the frequency of discharge of some units. It has been found (Angel, unpublished) that in the lightly anaesthetized animal, i.e. one with a flexion reflex just present, the effects of an electrical stimulus on the same unit may be different at different times, but that these units will still respond in only one way to a 'natural' stimulus such as pinching or rubbing the skin. Formerly (Angel & Dawson, 1963) it was suggested that the changes seen in the thalamic and cortical evoked potentials after a strong peripheral stimulus could have been due to at least three factors: (*a*) an excitatory reticular influence acting on the thalamic relay nucleus and/or sensory cortex, (*b*) a decreased cortical inhibition of the thalamic relay nucleus, or (*c*) a change in the responsive state of the cortex itself.

There is a large amount of evidence which shows that reticular stimulation is capable of modifying the transmission of information; in the spinal cord (Hagbarth & Fex, 1959), in the gracile nucleus (Hernández-Péon, Scherrer & Velasco, 1956) and in the thalamic somatosensory relay nucleus (King, Naquet & Magoun, 1957). In animals anaesthetized with trichloroethylene the latency of the cortical response was less, and the first negative wave larger than in animals anaesthetized with urethane (Angel & Dawson, 1963). It is interesting, therefore, that the rate of discharge of thalamic units whose frequency was increased after a peripheral stimulus, was greater in animals anaesthetized with trichloroethylene than in those anaesthetized with urethane. The discharge frequency of this type of unit was found to be directly related to the size of the early parts of the responses in the thalamic relay nucleus and cortex and to their latencies, so that when the frequency of the unit discharge increased the thalamic and cortical responses also increased in size, and their latencies were reduced. The increase in the reticular excitation could be conveyed by this type of thalamic unit.

Adrian (1954) has pointed out that it is more difficult to obtain a response from the sensory cortex, after a peripheral stimulus, in the lightly than in the deeply anaesthetized animal, and suggested that deep anaesthesia may suppress an inhibitory activity which is checking some or all of the signals at a lower level in the sensory pathway. A similar suggestion had been made previously by Head & Holmes (1911), who postulated that the hyperaesthesia they saw in patients with lesions of the lateral thalamic nuclei might be explained by supposing that the incoming information did not reach the cortex unaltered but had to 'pay toll' on its way from the periphery. They assumed that the cortex exerted an inhibitory control over the thalamus through the corticothalamic system of fibres described by Cajal (1909), and that this pathway had been interrupted by the lesions in their patients. Support for this hypothesis has been obtained by Iwama & Yamamoto (1961), who have shown that a single stimulus to the cortex impeded transmission through the ipsilateral thalamus for several hundred milliseconds, and also that ablation of the somatosensory cortex caused an increased responsiveness of the thalamus on the same side. Again, Ogden (1960) has shown that transmission through the ventrobasal thalamus was decreased after a penicillin spike had been recorded from the cortex. The behaviour of the type of thalamic unit whose frequency of discharge was decreased after peripheral stimulation would seem to be suitable for the mediation of an inhibitory cortical control over the thalamus. It has been shown in the present work that the size of the thalamic and cortical responses increased linearly as the discharge frequency of this type of thalamic unit fell. In addition when the discharge frequency of this type of unit is increased above the resting level the cortical and thalamic responses are decreased in size. Cortical stimulation increases the frequency of this type of unit (Angel, unpublished).

The question of whether a change in the responsive state of the cortex plays any part in the increase in size of the evoked cortical potentials will de dealt with fully in another paper. Suffice it to say that as far as can be determined the major factor found to increase the size of the cortical response is an increased transmission through the thalamic relay nucleus.

Units showing responses to noxious stimuli applied over a wide area of the body have been found in the posterior group of thalamic nuclei in cats (Poggio & Mountcastle, 1960) and in cats and monkeys (Whitlock & Perl, 1961; Perl & Whitlock, 1961). The units described in this paper were different from these in three major respects. They could not be excited by weak as well as strong stimuli, no unit showed an increase in frequency to stimulation of one peripheral site and a decrease to stimulation of another, and no unit had a receptive field which did not extend bilaterally over a large portion of the body surface. Kruger & Albe-Fessard (1960) in the cat and Whitlock & Perl (1961) in the monkey mention units in the thalamic reticular formation excited by stimuli to any part of the body surface; but whether they could be excited by other than noxious stimuli is not clear.

The word unit has been used in this paper to describe the elements studied in the thalamic reticular nuclei. It is thought that these units were in fact cells, since (*a*) they were obtained from a highly cellular region, (*b*) no responses like these were ever recorded from a region devoid of cells, e.g. the dorsal columns, and (*c*) these 'units' often gave injury discharges, which was never seen with the type of electrode used when recording from the dorsal columns.

SUMMARY

1. Two quite distinct types of cell were found in the thalamus at sites other than that of the thalamic sensory relay nucleus.

2. The first type showed an increased frequency of discharge after a strong peripheral stimulus, the second a decrease in its frequency of discharge.

3. The adequate stimulus for affecting these two types of thalamic cell was found to be a strong stimulus. Tapping or stroking the skin and joint rotation were found not to be effective.

4. The effect of a strong peripheral stimulus lasted for different times in animals anaesthetized with urethane or trichloroethylene.

5. In animals anaesthetized with trichloroethylene the effect of a standard strong peripheral stimulus lasted for 0·8–1·0 sec and the peak of the effect was seen 200–300 msec after the start of the stimulus. In animals anaesthetized with urethane the effect lasted for 2·5–4·0 sec and the peak of the effect occurred 300–600 msec after the start of the stimulus.

6. The changes seen in transmission in the dorsal-column sensory pathway at the levels of the thalamus and cortex run a parallel time course to the frequency changes seen in these two types of thalamic cell after a strong peripheral stimulus. This was so for both the anaesthetic agents used.

7. The change in the dorsal-column sensory pathway at the levels of the thalamus and cortex can be directly related to the changes of frequency of discharge of the two types of thalamic cell.

8. The two types of thalamic cell are found to be located in the nucleus reticularis thalami and in the nuclei ventralis pars dorsomedialis.

9. The significance of the changes seen in the frequency of discharge of the two types of thalamic cell is discussed.

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