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TIMING OF CORTICOFUGAL ACTIONS ON THE GRACILE AND CUNEATE NUCLEI OF THE CAT

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SUMMARY

1. A comparison is presented of the latencies of corticofugal effects from the contralateral somatosensory cortex (SI) onto the cat's dorsal column nuclei (d.c.n.) under pentobarbitone anaesthesia.

2. The latencies for transmission in the ascending pathway from d.c.n. to SI after stimulation within the gracile and cuneate nuclei were found to be 3·3 ms for the former and 2·8 ms for the latter.

3. The time courses of inhibition of a medial lemniscal mass response following cortical conditioning and evoked by stimulation of peripheral nerves were measured. All latencies were corrected to exclude the different times taken for stimuli to reach the nuclei from the two limbs. The optimal condition–test interval was 12 ms with a duration of 14·3 ms for the superficial radial nerve (s.r.n.) and 45 ms and 30 ms respectively for the medial plantar nerve (m.p.n.). In each case cortical conditioning inhibited the wave by about 50 %.

4. The effect of cortical conditioning upon spontaneously firing d.c.n. single units was investigated. For cuneate cells the mean latency was 6·8 ms and the mean duration 36·8 ms. For gracile cells the latency of onset of inhibition was 17·2 ms and its duration 129 ms. In 75 % of cells mixed effects were seen with facilitation preceding inhibition.

5. The latencies of 'corticofugal reflex' action on the gracile and cuneate nuclei after stimulation of the s.r.n. and m.p.n. were determined. The gracile response had a latency approximately 4 times that for the cuneate response.

6. The temporal asymmetry of these corticofugal effects suggests that the pathway is not purely a simple feed-back loop, but may be concerned in other physiological contexts, some of which are discussed.

INTRODUCTION

The origin of descending fibres from the cat's sensorimotor cortex to the dorsal column nuclei (d.c.n.) was shown anatomically by Kawana & Kusama (1964), and physiologically by Levitt, Carreras, Liu & Chambers (1964) to be arranged so that the cortical area which received afferents from the forelimb projected to the cuneate nucleus, and the hind-limb area to the gracile nucleus. This has been confirmed more recently with the retrograde horseradish peroxidase (HRP) technique by Berrevoets

& Kuypers (1975). Before the introduction of such retrograde anatomical techniques the precise localization within the cortex of these corticofugal cells could only be determined by activating them antidromically. Gordon & Miller (1969) stimulated within the d.c.n. and recorded antidromically from cells in the contralateral sensorimotor cortex. In a continuation of this work Brech, Gordon & Powell (1977) showed that the origin of corticogracile cells was mainly in area 3a while corticocuneate cells, although originating mostly in 3a, were also found in more rostral and caudal areas. They found that the latency for antidromic activation was less for the cuneate population than that for the gracile, showing the mean value to be 3 ms for seventeen corticocuneate cells and 6·9 ms for twenty-nine corticogracile cells. This contrasts with the ascending path, where we have shown that the latencies for evoked responses elicited by stimulating cuneate or gracile nuclei and recording from their primary receiving areas in contralateral sensorimotor cortex are nearly equal (see Results).

Several authors including Jabbur & Towe (1961), Gordon & Jukes (1964), and Levitt *et al.* (1964), have investigated corticofugal actions on the cat's d.c.n. with orthodromic techniques. However there has been no systematic comparison of the latencies of such effects. This paper presents such a study. It also seeks to avoid a possible objection to the antidromic technique – that the identification of cells projecting to a nucleus may have been inaccurate if the fibre was excited antidromically in a non-terminal region. Such an error is possible but unlikely since there was a clear separation in the cortex between corticogracile and corticocuneate cells.

If under physiological conditions there is corticofugal modulation of peripheral input to the cortex, then this modulation might be revealed as a 'reflex' by the synchronous activation of afferents in a peripheral sensory nerve. In 1962, Towe & Zimmerman did this and showed a putative 'corticofugal reflex' in the cuneate nucleus after stimulation of a forelimb nerve. In the present study a comparison of forelimb and hind limb 'corticofugal reflexes' is reported.

Preliminary accounts of some of this work have been published (Cole & Gordon, 1976*a*, *b*).

METHODS

Results are reported from experiments on twenty cats weighing 1·8–3·0 kg. Anaesthesia was induced with an intraperitoneal injection of 38 mg kg^{-1} pentobarbitone sodium and thereafter maintained with intravenous pentobarbitone at a level sufficient to prevent spontaneous movement or any movement in response to the experimental manipulation. In some single unit experiments cats were also given gallamine triethiodide and artificial pneumothoraces performed with subsequent mechanical ventilation to improve recording conditions; in some experiments the gallamine (8–12 mg) was given at approximately half-hour intervals and the level of anaesthesia checked before each dose. Body temperature was maintained at 38 °C by a thermostatically controlled blanket.

The d.c.n. were exposed and a laminectomy at C4 performed with subsequent division, with watchmakers' forceps, of the ipsilateral dorsolateral fascicle. For mass response experiments peripheral nerves were then exposed, placed on silver-wire electrodes, cut distally and covered in a mixture of liquid paraffin and petroleum jelly. Under these conditions the threshold remained constant for the duration of the experiment. The sensory nerves dissected were the superficial radial nerve (s.r.n.) from the forelimb and the medial plantar nerve (m.p.n.) from the hind limb. In some animals the deep radial nerve (d.r.n.) was also exposed for stimulation. The animal's head was then placed in a holder aligned to Horsley–Clarke co-ordinates and the contralateral sensorimotor and parietal cortex exposed through the cranium. The dura was incised and reflected and the exposed cortical surface protected with warm liquid paraffin.

In one group of experiments the output of the d.c.n. was measured as the response recorded from

the contralateral medial lemniscus. These will be referred to as 'mass response experiments'. A transverse grid of five needle electrodes mounted 1 mm apart was lowered into the brain at Horsley–Clarke frontal planes Anterior 3·5 or 4·0 until the medial lemniscus was reached; this position was established by stimulation through the grid electrodes and recording antidromic spikes from the contralateral d.c.n. The 'best' of the five electrodes was subsequently used for recording and one other grid electrode chosen as an indifferent electrode. The peripheral nerve stimulus was of a current strength two times threshold and duration 0·1–0·4 ms. This excited large A fibres but not A^{δ} fibres, a fact checked independently by recording from these peripheral nerves.

A silver-ball type electrode was moved around the surface of the cortex to locate the best point for conditioning. On finding this a needle electrode was inserted 1·5–5·0 mm. A pair of negative rectangular pulses 0·1–0·5 mA, 0·4 ms duration, 2 ms apart was used as a unipolar cortical stimulus. Experiments proceeded with the response to the peripheral test stimulus delivered at 0·2 Hz recorded from the contralateral medial lemniscus and averaged 2^4–2^6 times with an on-line Biomac 1000 (Data Industries Ltd.). Then the test stimulus was preceded by the cortical conditioning stimulus at set intervals before the test shock. Alternate runs continued with and without conditioning with progressive change in the condition–test interval. The results were corrected and are expressed such that the condition–test interval is the time by which the cortical stimulus precedes the arrival of the test response at the d.c.n. as determined with a surface electrode. Thus the conduction times from fore- and hind-limb nerves and from d.c.n. to the medial lemniscus have been measured and eliminated. All mass records were recorded on-line on an $X-Y$ plotter to avoid the distortions introduced by direct recording on magnetic tape.

In single unit experiments a recording micro-electrode was inserted in the d.c.n. 2·0–4·0 mm caudal to the obex. No peripheral nerves were dissected. Spontaneously firing d.c.n. cells were found and their receptive fields and projection into the contralateral medial lemniscus (by the method of antidromic stimulation and impulse collision) determined. Then the effect on spontaneously firing cells of a cortical stimulus, similar to that used above, was observed. Three types of cortical stimulus were employed, a double shock as above, a single one of 0·1–0·4 ms duration and a train of seven shocks of 0·4 ms duration and lasting 12 ms. The results were observed by sweep superposition on a storage oscilloscope and in addition stored on tape.

In experiments investigating the 'corticofugal reflex', anaesthesia was induced with halothane, nitrous oxide and oxygen and then maintained with $\alpha D(+)$-glucochloralose 70 mg kg^{-1}. The animal was prepared as before, recordings made from just below the surface of the d.c.n. with a coarse tungsten micro-electrode and averaged. The peripheral nerves were dissected free and maintained as described above. The contralateral sensorimotor cortex was exposed for subsequent cooling with ice-cold Ringer solution.

Sections were cut at 50 μm in the plane of insertion of electrodes into the brain stem and stained with Weil's Haematoxylin as described previously (Brown, Gordon & Kay, 1974). These were used to confirm the position of the tips of the electrodes in relation to the medial lemniscus.

RESULTS

Transmission time in the ascending path from dorsal column nuclei to somatosensory cortex

Fig. 1 shows two histograms, compiled from several studies in our laboratory over some years, in which the latencies for the antidromic response of gracile and cuneate cells projecting in the medial lemniscus are compared. The cats weighed between 1·8 and 2·2 kg and the antero-posterior position of the stimulating electrodes was at approximately the Horsley–Clarke frontal plane 4·5 ($\pm$0·5) in the contralateral brain stem. The figures have been 'corrected' for the distance above or below the middle of the nuclei (taken as 1·5 mm caudal to the obex) at which each cell was located, on the assumption that the distance between the stimulating electrodes and that point was 23 mm. It is possible that a few cells with inputs from muscle afferents, whose lemniscal axons have a shorter mean latency than cutaneous cells (Rosén, 1969), may have been inadvertently included in the cuneate sample. Even so, it will be seen that

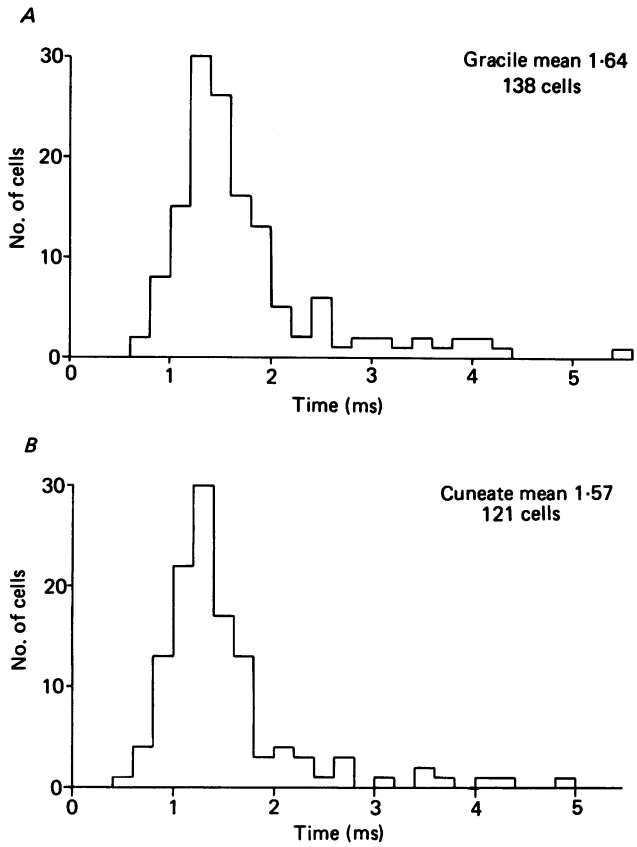

Fig. 1. Comparison of the latencies of antidromic response of populations of cuneate and gracile cutaneous cells to a twice-threshold stimulus delivered to the contralateral medial lemniscus. Data collated from many experiments (see text). Stimulating electrodes were at Horsley–Clarke frontal plane 4·5 (±0·5 mm). Latency values were corrected for positions of individual cells as explained in text. All responses were verified as truly antidromic by collision of orthodromic and antidromic impulses at critical timing. *A*, gracile cells; *B*, cuneate cells.

there is no significant difference between the latencies in these two populations, suggesting that lemniscal transmission time for the two nuclei is the same.

One experiment was designed to determine the shortest transmission time from each nucleus to the somatosensory cortex (SI). A low-resistance sharpened tungsten electrode was inserted in turn into the gracile and cuneate nuclei 3 mm caudal to the obex and about 0·8 mm deep. Single stimuli of 1·5 and 3 times threshold delivered through this electrode were used to plot the optimal area for the first component of the evoked potential in the contralateral SI cortex, recorded with a monopolar surface electrode. In the medial cortical area, responding only to gracile stimulation, the minimal latency observed was 3·3 ms and in the lateral and purely cuneate area it was 2·8 ms, with either size of stimulus. This difference of 0·5 ms is too small to have any significance compared with the large differences to be described in the corticofugal actions.

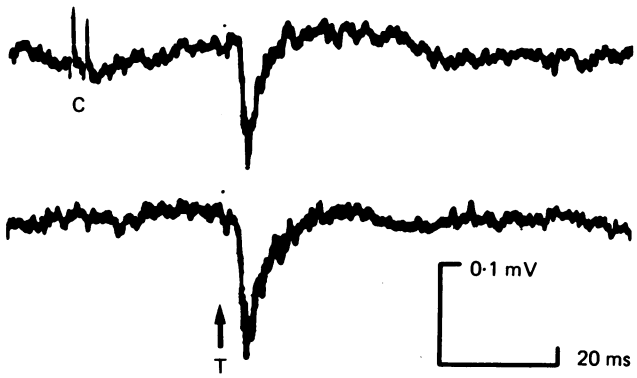

Fig. 2. The effect of a cortical conditioning stimulus (two shocks, 0·2 mA, 0·4 ms duration, 2 ms apart), on the mass response recorded from the contralateral medial lemniscus and evoked by stimulation of the deep radial nerve. Conditioned response uppermost, condition–test interval 25 ms. C: conditioning stimulus; T: test stimulus. Positivity downwards.

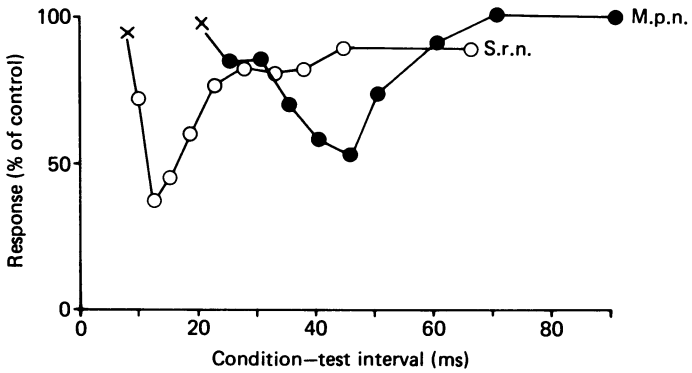

Fig. 3. The time courses of corticofugal inhibition onto medial lemniscal mass responses to peripheral stimulation of superficial radial nerve (s.r.n., open circles) and medial plantar nerve (m.p.n., filled circles). Time of delivery of test stimulus taken as time of arrival of peripheral nerve volley at d.c.n. Cortical stimulus two shocks, 0·2 mA, 0·4 ms duration, 2 ms apart. For the method of expression of size of response see text.

The effect of cortical conditioning upon lemniscal mass responses evoked by peripheral nerve stimulation

Medial lemniscal waves evoked from stimulation of a peripheral nerve were recorded as positive monophasic waves and averaged. The effect of a cortical conditioning stimulus on the test response was to reduce the latter's amplitude and width with a slight delay in the onset of the wave (Fig. 2).

Corticofugal inhibition from a forelimb area of sensorimotor cortex onto a s.r.n.-evoked medial lemniscal wave had a shorter latency and duration of action than corticofugal inhibition on a m.p.n.-evoked wave from stimulation of the hind-limb area of cortex (Fig. 3). An increase in cortical stimulus increased both the amount

and duration of inhibition (Fig. 4*A*). The results have been expressed in terms of the area of the wave representing the conditioned response as a percentage of the averaged areas of the two unconditioned responses elicited immediately before and after that conditioned response. These alternated as described in Methods.

With test stimuli delivered to the dorsal column at C4 level, latency of onset of corticofugal inhibition was equivalent to that of s.r.n. stimulation, but with longer

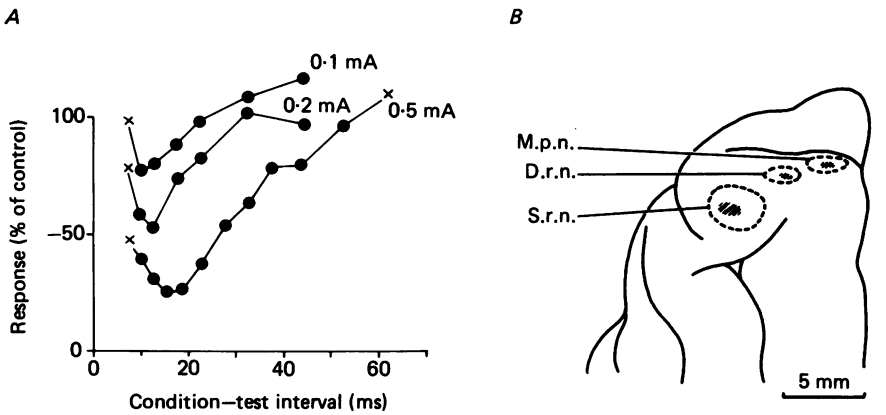

Fig. 4. *A*, the effect of cortical stimulus intensity upon the amount of corticofugal inhibition on a lemniscal mass response evoked by stimulation of the superficial radial nerve. Cortical stimulus two shocks, 0·4 ms duration, 2 ms apart. *B*, surface map of contralateral cortex to show areas (shaded) in which electrodes were inserted for maximal corticofugal effect on lemniscal mass response evoked by stimulation of peripheral nerves: s.r.n.: superficial radial nerve; d.r.n.: deep radial nerve; m.p.n.: medial plantar nerve.

time to peak and duration of inhibition. The position of cortical stimulation was in an area receiving distal forelimb cutaneous afferents. This equivalence presumably reflects the predominance of forelimb afferents at this level of the cord.

The best cortical points for corticofugal effects were found about 5 mm lateral to the mid line just caudal to the cruciate sulcus for the m.p.n.-evoked wave and caudal and lateral to the post-cruciate 'dimple' for the s.r.n.-evoked wave. By a systematic movement of the stimulating electrode around the cortex it was shown that these low threshold areas were well defined in the cortex (Fig. 4*B*). The area of cortex effective in inhibiting the s.r.n. was larger than that effective on the m.p.n.-evoked wave. This corresponds with the greater cortical representation of peripheral forelimb afferents and is in broad agreement with results from surface mapping of cortical waves evoked from peripheral stimulation (Clark, Landgren & Silfvenius, 1973). The use of needle electrodes for cortical stimulation at the strengths employed here would have produced an amount of current spread too large to allow any conclusion about the cytoarchitectonic pattern of best cortical areas for the observed corticofugal effects (see Stoney, Thompson & Asanuma, 1978).

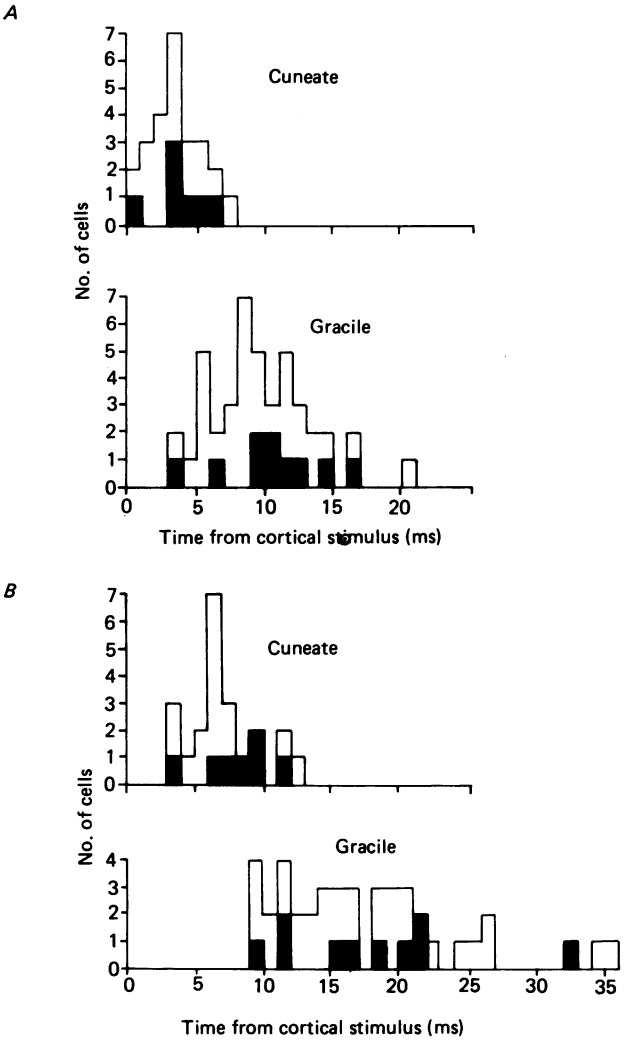

Fig. 5. The response of spontaneously firing gracile and cuneate cells to a double stimulus (0·4 ms duration, 2 ms apart, 0·05–0·3 mA) applied to the contralateral sensorimotor cortex. *A*, latency of onset of facilitation; *B*, latency of onset of inhibition. Filled squares: cells proven to project into the contralateral medial lemniscus.

Corticofugal effects on d.c.n. single units

In these experiments single cells were sampled from the d.c.n. with an inserted micro-electrode. It was difficult to inhibit d.c.n. cells excited by peripheral nerve stimulation and so spontaneously firing cells were investigated. This allowed analysis of a cell's receptive field but limited, and possibly biased, the population of cells sampled. Following a cortical conditioning stimulus, most cells (75%) responded initially with an increased firing frequency compared with the pre-stimulus rate and then a longer period of inhibition (Fig. 5). After this there was a return to the

spontaneous firing frequency although often there was a small 'rebound' facilitation immediately after the inhibition.

With each of the three types of cortical stimulus employed there was a statistically significant difference in the latencies of corticofugal facilitation and inhibition between the gracile and cuneate populations (Table 1). With one cortical shock there was a tendency for facilitation to occur later and for the period of inhibition to be

TABLE 1. Means of events in d.c.n. cells following stimulation of the contralateral sensorimotor cortex

	Cuneate		Gracile			
	n	ms	*n*	ms	Student's *t* test	Mann–Whitney *U* test
(A) Single cortical shock						
Latency of onset of facilitation	11	4·0	10	7·0	$0{\cdot}005 > P > 0{\cdot}0005$	$P < 0{\cdot}001$
Latency of onset of inhibition	11	7·6	10	17·7	$0{\cdot}01 > P > 0{\cdot}005$	$P < 0{\cdot}001$
Period of facilitation	10	3·9	10	10·4	$P > 0{\cdot}005$	$P < 0{\cdot}001$
Period of inhibition	14	29·0	10	140·7	$P > 0{\cdot}005$	
(B) Double cortical shock						
Latency of onset of facilitation	22	3·4	43	9·3	$P < 0{\cdot}0005$	Very significant
Latency of onset of inhibition	22	6·8	42	17·2	$P < 0{\cdot}0005$	Very significant
Period of facilitation	27	3·3	43	7·8	$P < 0{\cdot}0005$	$P < 0{\cdot}00023$
Period of inhibition	22	35·6	36	131·3	$P < 0{\cdot}0005$	
(C) Cortical tetanus						
Period of inhibition	26	62·4	24	103·1	$P < 0{\cdot}005$	

Statistical tests compare gracile and cuneate events. ms: duration of effect in milliseconds.

shorter than after a double shock. A tetanic stimulus produced a longer inhibitory period, but because of the duration of the stimulus artifact no information was gained about the latency of onset of that inhibition nor of any facilitation. The ease with which a cell was influenced from the cortex helped to determine the preferred stimulus used. Thus the cell samples are biased, with those cells easily inhibited with two shocks investigated further with a single cortical shock, and those cells less easily inhibited, with a train of stimuli. In those individual cells where all three types of cortical stimulus were used, the period of inhibition increased with increasing number of cortical shocks (i.e. one, two, or a tetanus). This suggested that failure to see this trend in populations of single units was due to sample bias.

The main investigation, as with the mass response, relied on a double cortical stimulus. Within this sample the various parameters, e.g. period of inhibition, latency of facilitation, were plotted against each other. No relationship emerged and so it is

not possible to say for instance that cells with a short facilitatory period also had a short period of inhibition.

The receptive fields for cuneate cells were mostly on the forepaw while those of the gracile cells had a larger scatter from low trunk to hind paw. Most were activated by hair stimulation with or without an additional input from dynamic mechano-receptors in pads, some by pad receptors alone. A plot of position of receptive field along the hind limb against latency of inhibition suggested a graded increase in the time of cortical effects proceeding distally along a limb in addition to the major temporal asymmetry between corticofugal effects on fore- and hind-limb cells, though our sample is insufficient to establish this conclusively.

For those d.c.n. cells in which both surface and intracortical stimuli were employed (in the same region of cortex), insertion of the electrode led to an increase in the inhibitory period and decrease in the latency and duration of other stimulus-dependent corticofugal effects.

The effect of moving the position of the cortical surface electrode was investigated mainly with cuneate cells. Unstable recording conditions often precluded full systematic cortical investigation. For most d.c.n. cells the results could be explained in terms of the stimulating electrode being moved around a single maximal cortical focus for corticofugal effects. The best cortical areas for corticofugal effects agreed with those found for the lemniscal responses. The number of cells proved to project into the contralateral medial lemniscus was insufficient to permit any conclusion about differential actions on projecting and non-projecting d.c.n. cells.

Corticofugal reflex

In these experiments the animals were maintained with α-chloralose. The peripheral nerves stimulated were the s.r.n. and m.p.n. Recordings were from the gracile and cuneate nuclei with inserted micro-electrodes. On-line averaging was used.

Towe & Zimmerman (1962) stimulated a peripheral nerve and recorded from the cuneate nucleus a primary negative wave N_1, latency 12–19 ms, and then a second wave N_0, after a further 18–20 ms, which was considered corticofugal in origin.

In the present work, the N_0 wave was absent at threshold for the primary N_1 wave. With increasing stimulus strength applied to the peripheral nerve the longer latency N_0 wave was observed (Fig. 6). The largest stimulus used was 2 times threshold for the N_1 wave. The latency for gracile effects was approximately 4 times that for cuneate effects (compare response latencies in Fig. 6*A* and *B*). The N_0 wave was abolished by cooling the contralateral sensorimotor cortex (see Methods). It also varied with frequency of stimulation, being maximal at 1 Hz and severely attenuated at 5 Hz. At higher stimulus strengths a third wave, designated N_2, was observed (Fig. 6*A*, middle and lower traces), and this may have represented a second or repeating corticofugal reflex. Some measure of the effectiveness of the corticofugal reflex may be gained from measuring the area under the curve for N_1 and N_0 waves and expressing the latter as a percentage of the former. For instance, in one experiment N_0/N_1 for the cuneate response was 76% and for the gracile 72%, suggesting that at least under the conditions of the experiment the relative effectiveness of the corticofugal reflex for the fore- and hind-limb nerves was similar.

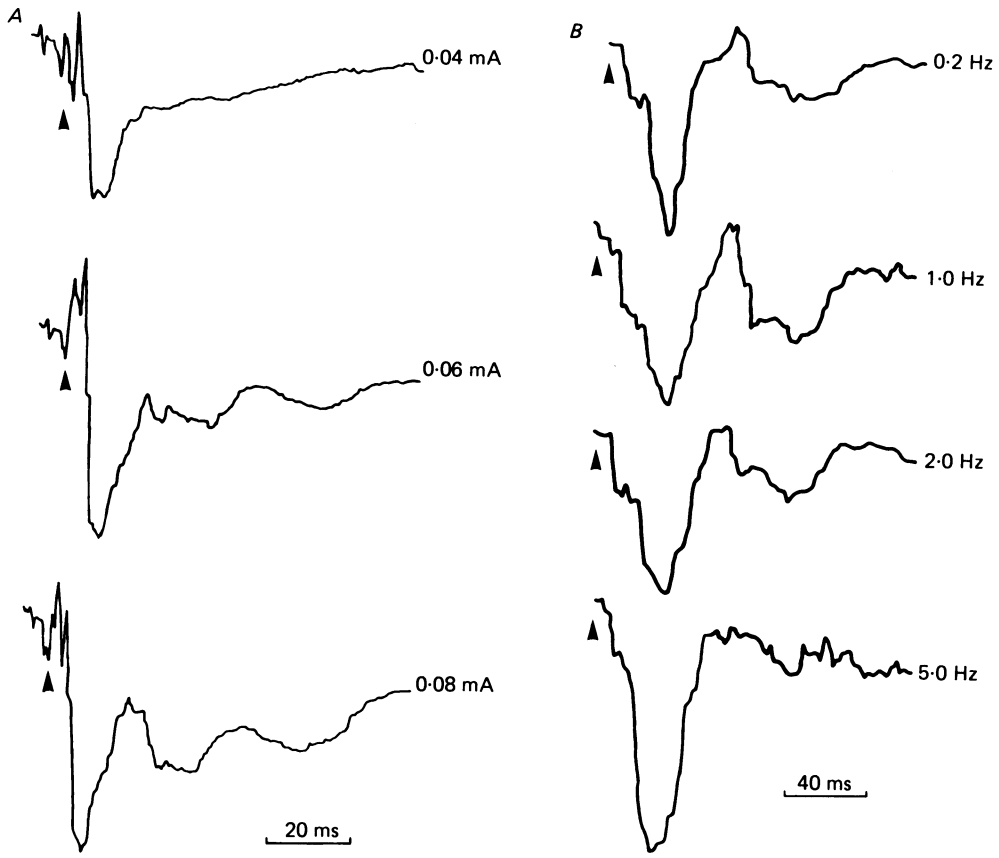

Fig. 6. 'The corticofugal reflex'. *A*, cuneate response to superficial radial nerve stimulation, showing the effect of intensity of peripheral nerve stimulus. Averaged 2^5 times, 0·2 Hz. *B*, gracile response to medial plantar nerve stimulation, showing the effect of frequency of stimulation. Stimulus intensity: 0·09 mA, threshold: 0·07 mA. Averaged 2^5 times.

DISCUSSION

The mass response and single unit studies show a temporal asymmetry of corticofugal effects onto the gracile and cuneate nuclei and so support the earlier work of Brech *et al.* (1977) with antidromic stimulation.

A comparison between the lemniscal records and those from the single unit studies shows quite a close correspondence in time between the cortifugal inhibitory envelope from the former and the histogram of inhibition from the single units. A small discrepancy is that the spontaneously firing d.c.n. cells showed a shorter latency of onset of inhibition after cortical stimulation than was found for the leading edge of the lemniscal inhibitory wave following s.r.n. or m.p.n. stimulation. There are several possible explanations for this. It is very unlikely to result from difference in the nature of the inputs, since the afferents concerned were of cutaneous origin in both cases. There might have been a difference in the latency of response of d.c.n. cells projecting and those not projecting into the contralateral medial lemniscus under the conditions

of cortical stimulation. The single unit work sampled both populations. Secondly a relationship was suggested between the positions of receptive fields of gracile cells and their latency of onset of corticofugal inhibition, 'hind-paw' cells having a longer latency than gracile cells with a receptive field on the thigh. The medial lemniscal wave was evoked from a m.p.n. stimulus representing an input from a restricted area of the hind paw whereas the gracile population constituted a sample of cells with fields more widely spaced along the limb.

A consistent observation in the single unit experiments was that rather than a single asymmetry, between the two nuclei, there was an additional one in that facilitation occurred before inhibition. There was no evidence of this in the medial lemniscal experiments. This may have been because it was masked by stimulus artifact at short condition–test intervals, or because the facilitatory component may have been a small part of the whole medial lemniscal wave. Certainly Gordon & Jukes (1964) described mixed cortical effects, i.e. facilitation and inhibition, but suggested that facilitation occurs more commonly among cells not projecting in the lemniscus.

One assumption in the present work is that gracile and cuneate cells were equally accessible to cortical stimuli. This is confirmed by there being no difference between thresholds of surface and intracortical stimulation applied to forelimb and hind-limb areas. The experimental procedure was designed to find similar numbers of affected gracile and cuneate cells rather than to reflect the absolute number in each nucleus. Since the total number of gracile cells is smaller, the medial lemniscal results may be skewed because a given cortical stimulus may have activated a greater proportion of the cells descending to the hind-limb nucleus than to the forelimb. That this was not a significant effect was suggested by the 'corticofugal reflex', which did not involve stimulating the cortex, because the size of the N_0/N_1 ratio (see Results) was the same for the two nuclei. Similarly if the forelimb population had a more secure ascending pathway it might be less easily affected from the cortex, or affected for less time. However, it can be seen from Fig. 2 that at least the inhibitory effect is equally powerful on both nuclei.

The observed asymmetry seems likely to be the result of anatomical differences within the forelimb and hind-limb corticofugal pathways. There may be differences in intracortical cell size, which may be linked to the cells' axonal diameters and in the diameter of axon collaterals, or in neuronal circuitry within the nuclei.

The electro-anatomical work of Brech *et al.* (1977) implied that the asymmetry in latency of antidromic conduction between the corticocuneate and corticogracile populations was due to differences in fibre size. More recent horseradish peroxidase investigations have not resolved the question. Berrevoets & Kuypers (1975) injected HRP into the gracile and cuneate nuclei and found label distributed in the soma of pyramidal cells mainly in lamina V of particularly areas 3a, 3b and 4 with some in areas 2 and 6. They commented that the cortical cells labelled after d.c.n. injection of HRP were slightly smaller than those in a population of similar cortical distribution which were labelled after HRP was injected into the spinal cord. In a double HRP and tritiated enzymatically inactivated HRP-labelling study, Rustioni & Hayes (1981) found cortical cells projecting to the d.c.n. alone to have a wide spectrum of perikaryal size (12–50 μm) compared with a population of cortical cells

presumed to project from cortex to d.c.n. and cord, which had a small range of sizes (24–42 μm). In neither study was mention made of differences in perikaryal size of cells in the fore- and hind-limb cortex which projected onto the d.c.n. The question of soma size of cells in the SI cortex projecting to the spinal cord has been studied by Groos, Ewing, Carter & Coulter (1978), who found no differences with HRP injections in cervical or lumbosacral levels. A similar study of cells projecting to the d.c.n. would be illuminating. Thus although there is no direct evidence at present that the asymmetry in latencies between corticocuneate and corticogracile effects is mediated through fibre size, some or all of it may be.

The original work of Magni, Melzack, Moruzzi & Smith (1959) found excitatory effects to be mediated through the pyramidal system. Other authors (Cesa-Bianchi & Sotgiu, 1969), have shown the extrapyramidal bulbar reticular system to be involved in corticofugal inhibition onto the d.c.n. Sotgiu & Marini (1977) with micro-ionophoresis of HRP into the cuneate nucleus have shown a connexion between that nucleus and nucleus gigantocellularis in the reticular area of the medulla. Evidence that corticofugal modulation at the d.c.n. occurs through pre- and post-synaptic effects comes from the work of Andersen, Eccles, Oshima & Schmidt (1964). Since the time courses of these effects differ, intraneuronal mechanisms in the two nuclei may be involved in the observed asymmetry.

Corticofugal modulation at the d.c.n. may be concerned in several physiological contexts. One theory of corticofugal action suggests a fusion of motor and sensory function. A cortical discharge initiating a movement would also modulate afferent return in relation to the sensory expectations of that movement. This could allow for both an increase in information transmission, e.g. during exploratory movements, and a decrease when sensory return was a predictable function of that movement. Evidence for such a theory has come from experiments reported from implanted electrodes in the medial lemniscus of conscious unanaesthetized cats (Ghez & Lenzi, 1970; Coulter & Thies, 1971; Coulter, 1974). These physiological experiments may indicate a possible role of active touch in spatial discrimination. It should not however be assumed that facilitation and inhibition as observed in the mass response necessarily indicate greater and lesser spatial acuity respectively: patterned inhibition is commonly regarded as causing increased contrast and thus acuity (see Gordon, 1978).

Another theoretical context for corticofugal modulation of sensory return from a movement comes from the work of Hulliger, Nordh, Thelin & Vallbo (1979). They found from percutaneous nerve fibre recordings in man that active movement causes a considerable amount of activity in skin receptors and considered the possibility that this might provide useful kinaesthetic information. While such information could be of value it is also possible that during some movements it would lead to confusion. In these circumstances its selective suppression would be an advantage and for first order afferents traversing the dorsal columns the d.c.n. would be the first place this could occur. This may be related to Rushton, Rothwell & Craggs (1981) finding that the somatosensory evoked potential in man from stimulation of a digital nerve is reduced in its second component (latency 45–55 ms) by movement of the stimulated digit.

Thus although the cortical stimulus employed in the present work was unphysio-

logical, being well above threshold and unnaturally synchronous, the differences in timing of corticofugal modulation at the d.c.n. so revealed suggest that these effects are not involved solely in a simple feed-back loop. Such temporal asymmetry in corticofugal effects may also be present elsewhere since while the ascending tracts may be studied separately, as in the present case, they are connected at segmental and medullary levels, and under natural conditions are likely to be intimately related.

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