The electromyographic silent period produced by supramaximal electrical stimulation in normal man

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SUMMARY The electromyographic silent period produced by supramaximal electrical stimulation of the median nerve was recorded in the abductor pollicis brevis muscle of four normal subjects during maximal isometric voluntary contraction. Except for an inconstant F response, electrical silence could usually be induced in the muscle from the twitch potential until the reappearance of uninterrupted voluntary activity. The silent period produced by stimulation at the wrist was approximately 25 msec longer than that produced by stimulation at the elbow and was independent of muscle tension. Further shortening of the muscle during the twitch contraction did not significantly alter the length of the silent period. A silent period in the abductor pollicis brevis muscle was also obtained after stimulation of the ulnar nerve, at the wrist and at the elbow. The onset of this period of silence was delayed, but it ended at the same time after the stimulus as the corresponding silent periods produced by median nerve stimulation. It is concluded that the end point of the silent period produced by supramaximal electrical stimulation of a mixed peripheral nerve is determined by an inhibitory spinal reflex, afferent impulses travelling in slowly-conducting fibres that are directly activated by the stimulus. Under these conditions the length of the silent period gives no indication of spindle activity in the muscle.

The electromyographic silent period (Merton, 1951) following electrical stimulation of the nerve to an actively contracting muscle is the resultant of several effects of the stimulus. It has been shown that the early part of the silent period is produced by antidromic impulses passing up the motor fibres (Merton, 1951; Herman, 1969). There has been general acceptance of the view that the end point of the silent period is determined by re-extension of the muscle spindles after the twitch contraction (Higgins and Lieberman, 1968a, b). The occurrence of normal silent periods in patients with the rigidity of Parkinsonism, for example, has been interpreted as evidence of normal gamma motor neurone activity in rigidity (Dietrichson, 1971; Higgins, Haidri and Wilbourn, 1971). However, voluntary activity is not dependent upon the presence of feed-

back signals from muscle spindles: a deafferented muscle can develop good voluntary contraction and the cessation of afferent impulses from spindles would not be expected to interrupt maximal voluntary contraction completely. The situation is different in the decerebrate cat, where tonic alpha motor neurone activity results mainly from a central drive on the gamma motoneurons; in such a preparation unloading of the spindles would necessarily terminate the activation of alpha motoneurons. In normal voluntary activity it is likely that alpha motoneurons are activated directly through the pyramidal system and indirectly via the gamma system, both systems working concurrently to produce contraction (Matthews, 1964; Vallbo, 1970). Direct alpha motoneurone activation is likely to be of particular importance in maximal isometric voluntary contraction, in which the amount of alpha motoneurone activity is not primarily determined by changes in muscle

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length. The purpose of the present study was to establish whether the end point of the silent period under these conditions is determined by direct stimulation of sensory nerve fibres or by activation of muscle receptors.

METHOD

Four normal male volunteers, aged between 23 and 31 years, were studied. After preparation of the skin with standard electrode jelly, skin-clip surface electrodes were placed 3 cm apart over the abductor pollicis brevis muscle. Stimulating electrodes 3 cm apart with the cathode distal to the anode were placed over the ulnar nerve at the lower end of the forearm and at the elbow, and the distance between the two sites of stimulation was measured. The subject was comfortably seated and the right upper limb was placed in a frame that held clamps for the hand and forearm. The palm of the hand was clamped between a vertical wooden plate and a wooden elliptical disc (diameters 15×7 cm) that could be screwed towards the plate from its mounting on the frame. The forearm was held in a stiff polyethylene sleeve from wrist to elbow; the sleeve was screwed to the frame and its diameter could be adjusted by inelastic tapes so that the forearm was held securely. The wrist and forearm were held in the neutral position while the elbow was semi-flexed.

An isometric tension transducer (Devices type

4150) was attached to the proximal phalanx of the thumb by steel wire. The transducer was modified by a mechanical fulcrum to give an extended range of up to 6N; the force applied during maximum contraction varied between subjects but was approximately 2.5 N. The circuit plan is shown in Fig. 1. The output from the transducer was fed through a Devices Transducer Function Unit (type 3559) and A.C. coupled to one channel of a storage oscilloscope (Tektronix RM 564) with a frequency response of $0.1-10^4$ Hz. The output from the surface electrodes was fed into a Devices A.C. High Gain Function Unit (type 3542), and the output was displayed on the second channel of the storage oscilloscope.

A data retrieval computer (Nuclear Chicago, type 7100), operating in the transient averaging mode, was used to average the data from 10 consecutive recordings. The purpose of the computer was partly to check the accuracy of the mean silent period values and partly to provide an averaged record that could confirm that individual traces were representative of a consistent and reproducible phenomenon. This computer can analyse unrectified signals only when they occur at the same point along the time base of a computer; random signals such as EMG signals would average to zero because of subtraction of negative from positive potentials over the course of several sweeps. The EMG signal from the high gain function unit was, therefore, full wave rectified with no smoothing, the frequency response of the

FIG. 1. Circuit plan of apparatus.

computer being $0.1\text{--}10^7$ Hz. In this way, time-locked periods of silence could clearly be identified. In some computer records the EMG base line shifted slightly during the silent period and it was not possible to detect from the record alone whether the shift was caused by slight EMG activity or by movement artefact during the silent period. Analysis of individual unrectified records (using the storage oscilloscope) confirmed that the end point of the silent period was not obscured by artefact. When the computer was in operation, a second channel was used to average the output from the transducer function unit.

The subject maintained maximal isometric abduction of the thumb against the transducer, the steadiness of the applied force being monitored by the subject and by the observer using the trace location device on the oscilloscope. A supramaximal stimulus was delivered from a Disa stimulator (type 14E11) which triggered the oscilloscope or the computer. A square wave electrical stimulus of 400 V lasting 0.2 msec was applied to the median nerve first at the wrist and then at the elbow. Further measurements of the silent period were made using the same stimulus superimposed upon moderate voluntary contraction; after a series of such readings the steel wire between the thumb and the tension transducer was replaced by an elastic band and further identical stimuli were superimposed upon a moderate voluntary contraction. The steel wire was then returned and the stimulating electrodes were moved to overlie the ulnar nerve at the wrist and at the elbow; the distance between the two sites of stimulation was measured. A stimulus of the same intensity was delivered to the ulnar nerve, first at the wrist and then at the elbow, while the subject maintained maximal abduction of the thumb as before. The electromyographic activity in the abductor pollicis brevis muscle and the output from the tension transducer were displayed first on the storage oscilloscope and photo-

graphed, enabling the changes in tension and electromyographic activity after successive stimuli to be compared. Series of 10 consecutive recordings were then averaged by the computer; the averaged traces were displayed on the storage tube of the computer and photographed. The length of the silent period was taken as the interval between the stimulus and the onset of uninterrupted voluntary activity, or the S-X interval (Higgins and Lieberman, 1968a).

To confirm that the recording electrodes were correctly positioned, the electromyographic activity occurring during abduction, adduction, flexion, and extension of the thumb against resistance was recorded. A typical record is shown in Fig. 2, from which it is clear that nearly all the recorded activity arose from the abductor and flexor pollicis brevis muscles. With surface electrodes it is not possible to record selectively from only one of these muscles and it is doubtful whether they can be selectively contracted by a normal subject, particularly during maximum effort. Fig. 2 also shows that interference from the adductor pollicis brevis muscle (supplied by the ulnar nerve) could not have obscured or mimicked the activity obtained from the abductor pollicis brevis muscle during the recordings.

RESULTS

The silent period (S-X interval, Fig. 3) produced by supramaximal stimulation of the median nerve at the wrist during maximal isometric contraction was reasonably constant for each subject; the intra-individual variation can be seen in Table 1, which shows the full data obtained from the four subjects (numbered 1-4) during series of 10 consecutive stimulations. The mean length of the silent period for the four subjects was approximately 103 msec, with a range of 96 to 113 msec. When the strength of the basal contraction was reduced or the thumb allowed to move during the twitch contraction, the silent period altered by less than 3 msec in three of the subjects, though the fourth showed prolongation of his silent period by 8 msec during isotonic basal contraction (Table 1, Figs 3 and 4). In all subjects, the silent period produced by stimulation at the elbow ended earlier than the silent period produced by stimulation at the wrist, the mean difference being approximately 25 msec. Stimulation of the median nerve usually produced silence in the muscle immediately after the twitch response and this silence continued, except for the inconstant F response and occa-

FIG. 2. Electromyograms from surface electrodes over the abductor pollicis brevis muscle during attempts by subject to move the thumb against resistance in the directions shown. For discussion see text.

FIG. 3. Individual records from the same subject showing effect of stimulation of the median nerve at the wrist (A) and elbow (B) during maximal isometric contraction of the abductor pollicis brevis muscle. Tension (upper traces) and surface electromyogram (lower traces). Stimulus applied at S. F wave at F. Occasional breakthrough voluntary activity at V. Silent period ends at X. The S-X interval is independent of tension changes occurring after the stimulus but is shorter after stimulation at the elbow.

TABLE 1
SILENT PERIODS RECORDED AFTER STIMULATION OF THE MEDIAN NERVE

Basal contraction		Maximal isometric								Moderate isometric				Moderate isotonic			
Site of stimulation		Wrist				Elbow				Wrist				Wrist			
Subject		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Silent periods (S-X intervals, msec)		116	98	108	96	96	88	64	76	116	98	98	100	106	98	108	108
		110	96	104	100	96	84	56	74	122	98	98	100	118	96	112	106
		112	94	108	94	96	80	56	78	118	110	106	110	122	96	106	114
		110	94	108	96	94	88	56	74	116	90	102	104	118	96	106	116
		114	94	100	104	102	78	64	70	108	100	108	100	110	106	100	108
		110	96	104	100	94	78	60	74	116	96	100	94	116	100	100	108
		112	94	102	98	104	78	54	76	112	96	108	106	108	100	108	106
		118	98	100	98	94	78	60	78	110	100	108	106	106	100	100	112
		120	98	104	94	92	84	54	74	112	98	106	106	116	96	110	112
		108	100	100	96	94	78	54	70	116	96	102	96	114	102	104	116
Individual means (msec)		113.0	96.0	103.8	97.6	96.2	81.4	57.8	74.4	114.6	98.2	104.6	102.2	113.4	99.0	105.4	110.6
Mean for group (msec)		102.6				77.5				104.9				107.1

FIG. 4. Effect of stimulation of the median nerve at the wrist during maximal isometric contraction. A, moderate isometric contraction B and moderate contraction against an elastic resistance C; effect of stimulation at the elbow during maximal isometric contraction D. Tension (upper trace in each figure) and electromyogram (lower trace): averaged effect of 10 stimulations, with standard calibration in all figures. Stimulus applied at S. Silent period ends at X. The S-X interval is independent of the nature of the contraction at the time of the stimulus (A, B, C) but is shorter after stimulation at the elbow (D).

sional breakthrough voluntary activity, until the onset of uninterrupted voluntary activity. The presence of F or of breakthrough activity did not appear to alter the end point of the silent period in this series of observations (Fig. 3).

Stimulation of the ulnar nerve, which does not normally supply the abductor pollicis brevis muscle, also produced a silent period in the muscle. The full data are given in Table 2. The onset of this electrical silence (designated 'O') was delayed for about 65 msec after delivery of the stimulus at the wrist; the onset of this silent period occurred approximately 18 msec earlier

when the ulnar nerve was stimulated at the elbow than when it was stimulated at the wrist, while the end point occurred approximately 21 msec earlier. Although the hand was clamped as firmly as possible and maximal isometric contraction was attempted, slight movement of the hand could not be avoided because of the nature of the soft tissues. Movement during the twitch contraction was noticeable after stimulation at the elbow because of the other muscles activated by stimulation there; this movement was responsible for the difference between tension changes recorded after stimulation at the wrist and those

TABLE 2

SILENT PERIODS RECORDED AFTER STIMULATION OF ULNAR NERVE DURING MAXIMAL ISOMETRIC CONTRACTION

Site of stimulation		Wrist								Elbow							
Subject		1		2		3		4		1		2		3		4	
Silent period: interval measured		S-O	S-X	S-O	S-X	S-O	S-X	S-O	S-X	S-O	S-X	S-O	S-X	S-O	S-X	S-O	S-X
Times (msec)	66	108	38	95	72	102	80	106		60	100	32	76	44	74	64	88
	65	104	38	96	72	108	74	100		52	96	32	80	44	74	56	78
	66	112	38	104	80	104	80	112		52	100	30	76	48	72	56	78
	66	116	38	98	80	94	80	110		54	94	28	80	50	70	60	80
	68	112	38	98	80	106	78	100		52	100	30	84	50	68	56	78
	70	112	38	96	72	106	76	100		40	104	30	80	52	72	60	78
	70	110	42	100	80	104	74	102		40	100	26	80	50	72	60	84
	68	116	38	96	72	96	78	112		52	98	30	84	50	70	56	80
	68	116	38	96	76	93	80	108		54	100	32	78	50	70	58	82
	68	108	36	98	76	96	78	110		48	100	26	80	52	74	60	82
Individual means (msec)		67.5	111.4	38.2	97.8	76.0	101.4	77.8	106.2	50.4	99.2	30.0	80.8	49.0	71.6	58.6	80.8
Mean for group (msec)		S-O = 64.9				S-X = 104.2				S-O = 47.0				S-X = 83.1			

S-O: time between stimulus and onset of silent period. S-X: time between stimulus and end of silent period.

FIG. 5. Individual records from the same subject showing effect of stimulation of the ulnar nerve at the wrist (A) and elbow (B) during maximum isometric contraction of the abductor pollicis brevis muscle. Tension (upper traces) and surface electromyogram (lower traces). Stimulus applied at S. Period of silence begins at O and ends at X. Both the S-O and S-X intervals are shorter after stimulation at the elbow.

FIG. 6. Effect of stimulation of the ulnar nerve at the wrist A, and at the elbow B, during maximal isometric contraction of the abductor pollicis brevis muscle. Tension (upper trace in each figure) and electromyogram (lower trace): averaged effect of 10 stimulations. Stimulus applied at S. Silent period ends at X. The S-X interval is shorter after stimulation at the elbow.

recorded after stimulation at the elbow (Figs 5 and 6). There was no consistent relationship between tension changes in the muscle and the end point of the silent period, either when successive recordings were compared or when they were averaged. Stimulation of ulnar and median nerves at the wrist produced silent periods with similar end points, and the same was true for stimulation at the elbow. The onset of the silent period, however, was delayed for approximately 65 msec after stimulating the ulnar nerve at the wrist and for 47 msec after stimulation of the ulnar nerve at the elbow. After median nerve

stimulation, the first part of the silent period (immediately after the twitch response) presumably resulted from an antidromic volley that would be produced in the motor neurones supplying the abductor pollicis brevis muscle by direct stimulation of the median nerve but not by stimulation of the ulnar nerve.

DISCUSSION

These findings indicate that the length of the muscle silent period (S-X interval) after supra-maximal stimulation of a mixed peripheral nerve is not related to activation of spindle receptors by changes in muscle length or to activation of Golgi tension receptors. The observations confirm previous reports that the end point of the silent period is consistent for an individual whether the contraction is isometric or isotonic, and is independent of the twitch amplitude (Higgins and Lieberman, 1968a, b; Dietrichson, 1971; Higgins *et al.*, 1971). A small stimulus can produce a silent period during gentle contraction but a larger stimulus is required to inhibit maximal contraction; the end point of the silent period, however, is normally constant and can not be attributed to the activation of spindle receptors or Golgi tendon organs, because the timing and intensity of such activation would

TABLE 3
SHORTENING OF SILENT PERIODS PRODUCED BY PROXIMAL STIMULATION, SHOWING IMPLIED CONDUCTION VELOCITY OF AFFERENT IMPULSE

Subject	Nerve stimulated	Differences between S-X interval obtained at wrist and elbow (msec)	Conduction velocity (msec)
1	Median	17.2	14.0
	Ulnar	12.2	21.3
2	Median	14.6	15.6
	Ulnar	17.0	15.4
3	Median	45.0	5.4
	Ulnar	30.2	8.8
4	Median	23.2	11.2
	Ulnar	25.4	11.4

reflect the timing and tension changes of the twitch response. Furthermore, the silent period produced by stimulation at the elbow was approximately 25 msec shorter than that produced by stimulation at the wrist despite the

increased latency of the twitch response. This suggests that the impulses are carried by slowly-conducting nerve fibres at a rate of about 13 m/sec (Table 3). This is the rate of conduction of delta (pain and temperature) fibres.

The occurrence of a silent period in the abductor pollicis brevis muscle after stimulation of the ulnar nerve at the wrist, or of the radial nerve, was first noted by Liberson (1962). Stimulation of the sural nerve may produce silent periods in the ipsilateral rectus femoris, gastrocnemius, and tibialis anterior muscles (Morris, Pollock, and Hinchcliffe, 1968). Such findings indicate that the afferent volley produced by electrical stimulation inhibits motoneurons serving adjacent localities in the limb. Inhibition has been demonstrated as a result of electrical rather than physiological stimulation, and the physiological role of the pathways involved is obscure. There is no direct evidence that physiological activity in delta sensory fibres has an inhibitory effect upon regional flexor motoneurons (Matthews, 1972). However, the sensitivity of spinal reflexes is known to be controlled by supraspinal centres (Lundberg, 1967). The silent period is prolonged in patients with Parkinsonism, but returns to normal when the tremor is abolished by levodopa (McLellan, 1972). This facilitation of the silent period reflex raises the possibility that ordinary sensory stimuli in Parkinsonism might have an inhibitory effect upon motoneurone activity, increasing the tendency to synchronization and so contributing to the generation of resting tremor (Simpson, 1966).

The end point of the muscle silent period produced by supramaximal electrical stimulation of a mixed peripheral nerve appears to reflect the activity of an inhibitory spinal reflex system, and gives no indication of spindle activity in the muscle.

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