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AN ANALYSIS OF THE FREQUENCIES OF FINGER TREMOR IN HEALTHY SUBJECTS

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It has long been known that muscular activity even in healthy subjects is associated with tremor, but the reason for this association has not been clear. The present investigation was undertaken in the hope of throwing more light on the mechanisms determining tremor frequency. Since individual motor units are known to fire at frequencies below that necessary to produce a fused tetanus, one possibility is that tremor may represent the pattern of firing rates of the motor units. On this view, the normal smoothness of the myogram depends on the asynchronous discharge of different motor units and tremor is to be regarded as a partial failure in this asynchrony. When the tension exerted by the muscle is increased, the firing rates will also increase, particularly if the muscle is contracting minimally (Lindsley, 1935; Weddell, Feinstein & Pattle, 1944; Bigland & Lippold, 1954), and the tremor rate would be expected to alter accordingly. Many workers, however, following Schäfer (1886), report a surprisingly constant tremor rate with a frequency of about 10 c/s. In the present experiments the frequency of tremor has been recorded in different subjects and at different strengths of muscular contraction and has been found to show little variation.

This regular rhythm may arise in some part of the central nervous system above the anterior horn cell, as many workers have believed, but it is also possible that it is produced in the reflex arc. The stretch reflex, like other servo-mechanisms, may exhibit instability and oscillate at a particular frequency, related to the delay round the loop. If the period of oscillation in the muscle is twice as long as the delay round the loop, the negative feed-back will become positive because its phase is reversed by the delay round the loop, and in this case the oscillation may be self-maintained. (This is only strictly true of a servo with linear components, but will serve as an approximation.) The delay

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includes both conduction time in the arc and the time taken for the mechanical response of the muscle to get under way. Clonus, which occurs pathologically in conditions where the reflexes are brisk (and the loop gain high), may well be an example of such instability on a gross scale. In the present experiments an attempt has been made to correlate normal tremor in different individuals with stretch reflex activity; no correlation has been detected, but this is not considered as conclusive as if the opposite result had been obtained.

Apart from any component of tremor produced by the activity of the motor units, it seemed possible that the mechanical properties of the trembling part might contribute a 'natural frequency' of oscillation to the tremor, similar to the resonant frequency of a vibrating reed or a tuning fork. In the recordings of finger tremor described in this paper, the index finger was held out under a tension determined largely by the weight of the finger and the degree of voluntary innervation, and in such circumstances it can be shown that the finger has a resonant frequency (the 'natural frequency') which is seen in the die-away oscillations following a sharp tap or flick and alters when weights are added to the moving part. The possible appearance of this 'natural frequency' in the frequency spectrum of physiological tremor has been investigated by recording tremor frequencies with different loads on the finger. The change observed in the 'natural frequency' is not accompanied by any comparable change in tremor frequency, so that mechanical factors appear unimportant.

METHODS

Any method of investigating tremor should, if possible, use a system free from inertia, as the forces concerned are small and any mechanical damping can be expected greatly to modify the tremor. In the apparatus used here the finger is made to interrupt the lower part of a parallel beam of light, playing on a vertical slit in a black screen, and the light passing through this slit is focused on the cathode of a photocell. The potential derived from this cell, which is a measure of the amount of slit covered by the finger at any instant, is fed by a cathode-follower to a high-gain pentode with anode to grid feed-back. By this means, good linearity ($\pm 1\%$) is obtained to the a.c. signal over a wide range of d.c. levels corresponding to the shadow of the finger falling on the slit at different heights. In practice, linearity is determined by the uniformity of the light beam, which gives a response within 5% for a 1 mm deflexion over the whole length of the slit. The pre-amplifier output is fed via a single capacitor coupling to a d.c. amplifier with an available gain of 10,000, the output of which drives both an oscilloscope and a pen recorder. A second channel from the pre-amplifier is subjected to differentiation before being fed to a second d.c. amplifier, the output thus representing angular finger velocity. The differentiating circuit is of the cathode-follower type, the current through a triode being employed to charge a condenser in the cathode (Gray, 1948). In the present series of experiments displacement and velocity traces have been recorded simultaneously throughout all the experiments and both traces have been subjected to frequency analysis. As it was desirable to record accurately down to 1·5 c/s a time constant of 8 sec was used for the displacement record; that for velocity was 4 sec; the h.f. response of the apparatus was flat up to 1000 c/s. For frequency analysis the output from the pen recording either position or velocity was fed into an Ediswan low-frequency analyser (Baldock & Grey Walter, 1946), the output being presented in the form of a series of pen deflexions, recording the frequency analysis as a histogram over the tremor record to which it applies (Fig. 1).

The experimental subjects were members of the medical, nursing, technical, secretarial and domestic staff of the hospital, their ages ranging from 17 to 61. During recording the subject sat comfortably with the forearm and hand supported on an arm rest and a sponge rubber pad under the palm of the hand; he was asked to hold out the right forefinger horizontally in the beam and, as far as possible, to try and keep it in the same place, but no especial concentration was called for, and the finger was not to be held unduly rigid. Recordings with and without splinting of the interphalangeal joints with cellulose tape showed that there was no significant difference in the records obtained; almost all the tremor movement takes place at the metacarpophalangeal joint. When it was desired to increase the inertia of the finger additional weights were bound with cellulose tape beneath the terminal phalanx.

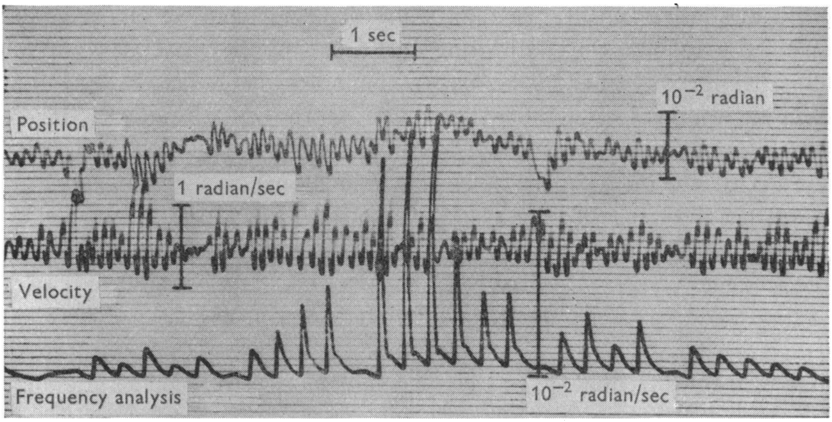

Fig. 1. Section of record of finger tremor in an individual subject, recorded from the right index with a 100 g weight strapped to the terminal phalanx. In the upper trace, amplitude is proportional to displacement, in the middle one to velocity. The lowest trace is an analysis of the relative amplitude of frequencies present between 1·5 and 30 c/s in the velocity trace during the 10 sec period covered by the analysis. The calibration of the frequency analysis which is in absolute units applies only to the resonators between 5 and 15 c/s which are all of equal band-width.

In each subject finger tremor has been analysed during five 10 sec periods for displacement and velocity, and as a prelude to statistical treatment the mean values have been expressed in arbitrary units of angular displacement or angular velocity at the metacarpophalangeal joint. As it was desired to compare the analyses with an input of 'white noise', i.e. equal activity at all frequencies, the analyses have been corrected to the form they would have if all the resonators in the analyser had equal band-width. The original finger movements were measured in radians or radians per second about the knuckle joint, but because the amplitude recorded by each filter depends on the effective band-width, and the correction has been made only for variations in band-width, the final result is not in absolute units.

RESULTS

Mean tremor levels for the two sexes. An analysis of the frequencies present between 1·5 and 30 c/s was carried out in forty-six healthy subjects, twenty-six men and twenty women. Both displacement and velocity records were analysed over separate periods of 50 sec., and the mean frequency spectra for the two groups are shown in Figs. 2 and 3. The curve for men is similar to that for women. However, these mean curves conceal a wide difference in average amplitude between the individual subjects in each group, which varied in extreme cases by a factor of 20. In each subject there was also some variation in tremor amplitude from one 10 sec period to the next, but this was of a relatively low order, 5:1 at most.

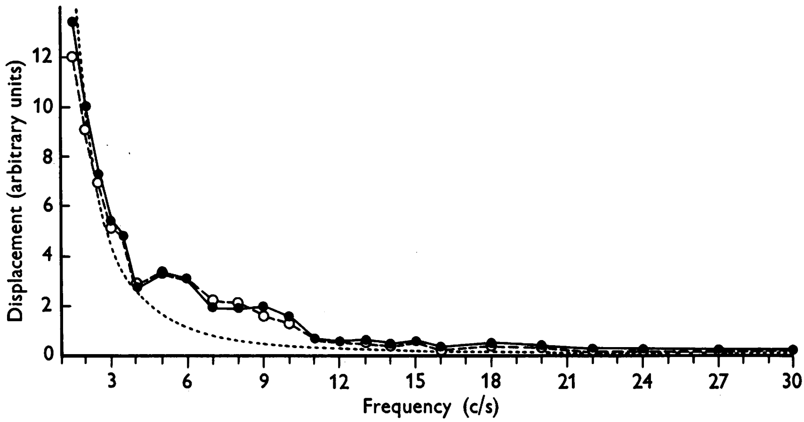

Fig. 2. Mean spectrum of finger tremor frequencies for twenty-six men ○ and for twenty women ●, obtained from an analysis of finger displacement. Dotted line represents an equal force curve (for explanation see text).

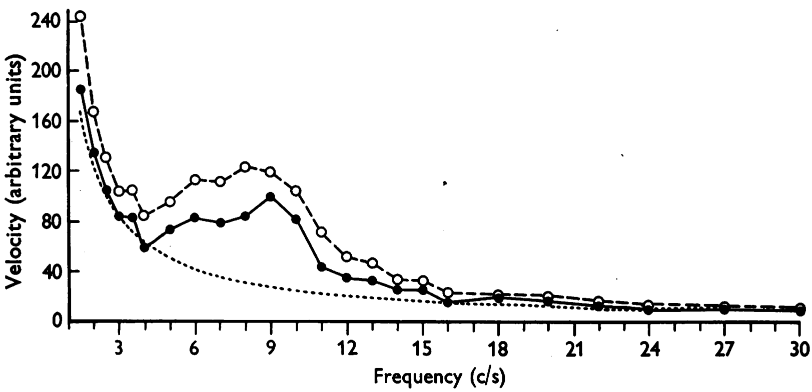

Fig. 3. Mean spectrum of tremor frequencies for twenty-six men ○ and for twenty women ●, obtained from an analysis of finger velocity. Dotted line represents an equal force curve.

Tremor frequencies in groups with different mean amplitudes. In view of the wide scatter of amplitude within the groups, the similarity between the spectra for men and women might have been due to a relatively small number of individuals with high amplitude of tremor. The readings were therefore rearranged in three new groups, representing high, medium and low amplitudes of tremor, the subjects having been first arranged in rank order according to the total amplitude of tremor (calculated by summing the amplitude at all frequencies between 1·5 and 30 c/s). To obtain three groups of equal size, one subject who had the highest tremor level was omitted. The means for the three groups are shown in Figs. 4 and 5. There is a marked peak frequency at 9 c/s in the velocity trace of the group showing the most tremor which is not

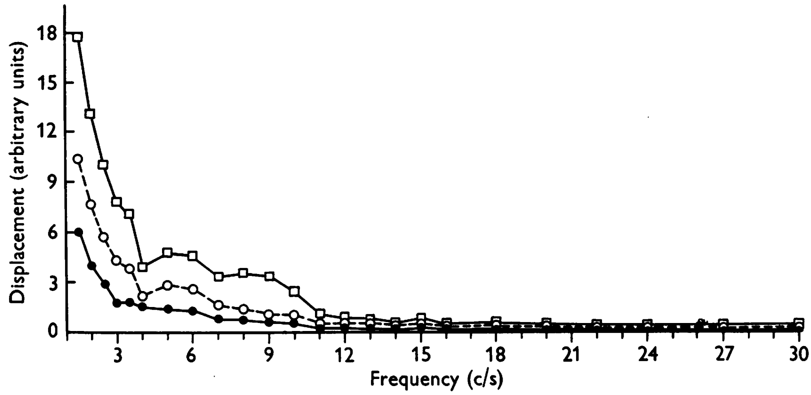

Fig. 4. Mean spectra of finger tremor frequencies in three groups showing high, medium and low amplitude of tremor respectively. Analysis of finger displacement record.

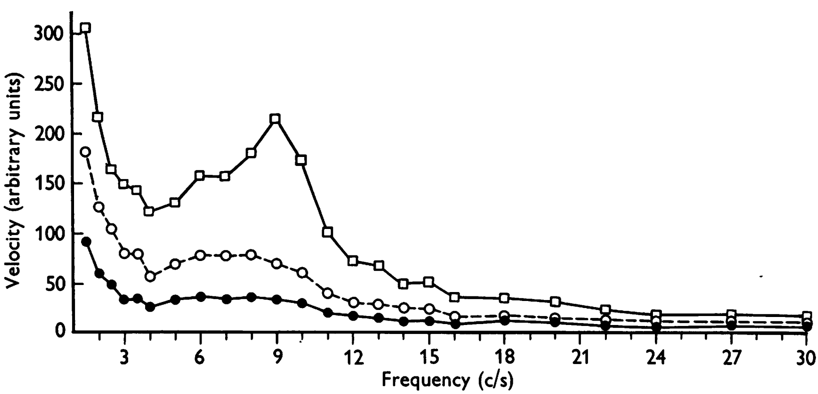

Fig. 5. Mean spectra of finger tremor frequencies in three groups showing high, medium and low amplitude of tremor respectively. Analysis of finger velocity record. Note similarity of tremor frequencies present in all three spectra, in spite of widely differing amplitude.

seen in the other two, but apart from this there does not appear to be any great difference in the frequencies present. The range of frequencies characteristic of finger tremor may be said to remain fairly constant at widely differing amplitudes.

Displacement and velocity compared. The appearance of an analysis of frequencies made from a record of displacement differs from one of the velocity record (Figs. 2, 3). They may be compared with the theoretical curve of 'equal force' (or, more strictly, turning moment) as shown by the dotted line in Figs. 2 and 3. In both these records there is a well-marked divergence from this curve between 5 and 15 c/s. Since $F \propto ma$ and the mass (m) remains for practical purposes constant, equal force (F) is equivalent to equal acceleration (a) at all frequencies. Acceleration is proportional to displacement × frequency², and to velocity × frequency. Hence, for equal sinusoidal fluctuations of force at all frequencies, displacement amplitudes fall off as the square of the frequency, and velocity amplitudes only as the frequency. The result is that the higher frequencies of tremor appear larger in the velocity trace, and the equal-force curve falls off less steeply (Fig. 3).

The deviations from this curve, which represents a 'random' input, show that external forces are acting on the system at the frequencies concerned or, alternatively, that there are resonances at these frequencies. In both displacement and velocity records, a band of activity from 5 to 15 c/s is demonstrated, but there is a shift on the apparent peak frequency from 5 c/s in the former to 9 c/s in the latter. This can be misleading if the records are being analysed by simple visual inspection. It is clearly not adequate to report tremor as being of one particular frequency, as has often been done by past workers, unless it is made clear that either displacement or its first or

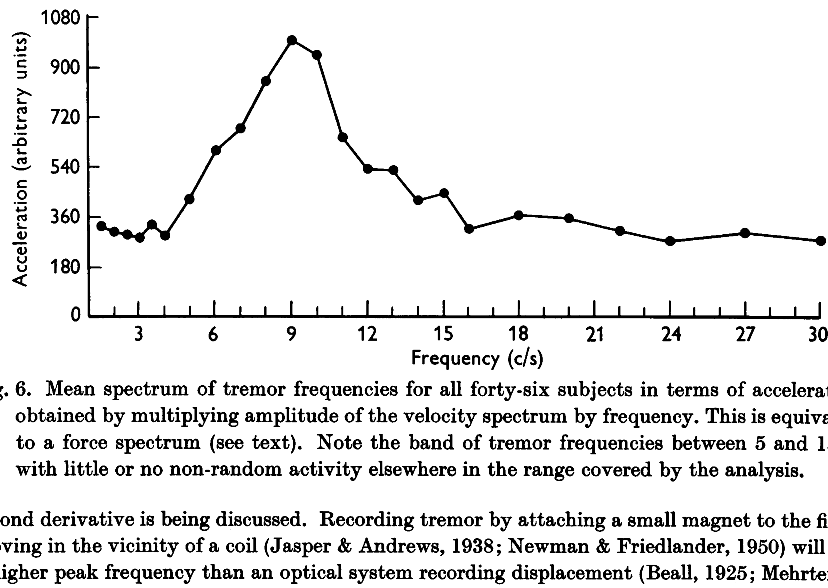

Fig. 6. Mean spectrum of tremor frequencies for all forty-six subjects in terms of acceleration, obtained by multiplying amplitude of the velocity spectrum by frequency. This is equivalent to a force spectrum (see text). Note the band of tremor frequencies between 5 and 15 c/s with little or no non-random activity elsewhere in the range covered by the analysis.

second derivative is being discussed. Recording tremor by attaching a small magnet to the finger moving in the vicinity of a coil (Jasper & Andrews, 1938; Newman & Friedlander, 1950) will give a higher peak frequency than an optical system recording displacement (Beall, 1925; Mehrtens & Pouppirt, 1928), since the former method records velocity, viz. the rate of cutting of the lines of force, while the latter records only change of position.

By multiplying velocity by frequency, a force spectrum is obtained (Fig. 6) which brings out more clearly the fact that finger tremor in this series represents quite a clear-cut band of frequencies between 5 and 15 c/s superimposed on a 'flat' base line.

The 'natural frequency' of the finger and the effect of added weights

The effect of mechanical factors on the frequency of oscillation of the finger (its 'natural frequency') has been investigated by giving sharp taps over the nail of the index finger (held out in the beam as in the tremor recording) and measuring the average period of the die-away oscillations which followed the tap. These were found to give consistent results provided the initial deflexion following the tap was ignored. Recordings were taken in this way on each subject with no weight, 50 and 100 g beneath the terminal phalanx. As well as increasing the inertia, the added weight would obviously increase the tension under which the finger was held and lead to increased muscular activity. The added weights would therefore be expected to reduce any frequency component of tremor determined by mechanical resonances and to increase, if anything, any frequency component due to motor unit discharge.

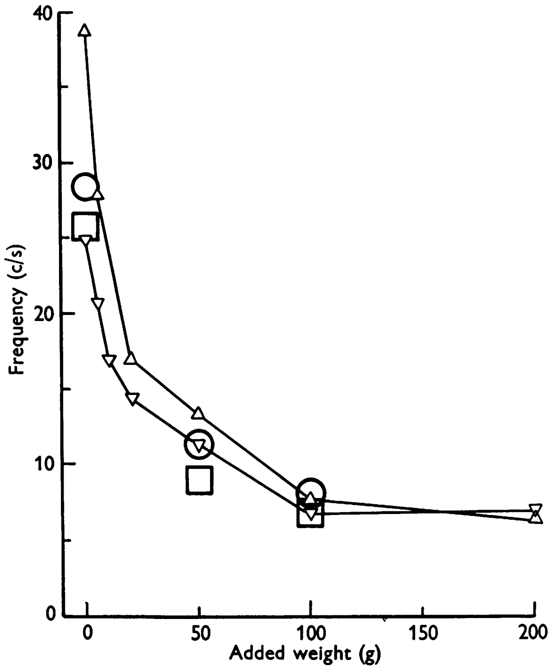

Fig. 7. Average frequency of the die-away oscillations following a sharp tap to the finger, with the finger unloaded and with various weights. ○, mean frequency for all men in group; □, mean frequency for all women in group; ▽, △, two individuals with a fuller series of points. Compare with Fig. 8.

The mean 'natural frequency' of the unloaded finger for the whole group was 27·4 c/s (S.D. 6·64). The additional loading of the finger with 50 g brought this down to 10·4 c/s (S.D. 2·69) and with 100 g to 7·6 c/s (S.D. 1·63). In Fig. 7 the mean frequency for men and women has been plotted separately. For these readings each subject was instructed to hold his finger out at the same tension as in the tremor record. Check observations on a number of subjects showed that minor changes in tension had little effect on the frequency, though a considerable increase could be obtained by telling the subject to hold out the finger as rigidly as possible.

Allowing for experimental error, the frequency appears to show a reciprocal relationship with the square root of the added mass, which is what would be expected in a simple mechanical system, e.g. a vibrating reed; thus the frequency falls off more steeply with the first 50 g than with the second. A fuller series of points for different attached weights has been obtained on several individuals and confirms this result. Values for two individuals are plotted in Fig. 7. For the present investigation, however, the essential point is that there is a large change in the mechanical resonance of the part, the magnitude of which is mirrored in the change of 'natural frequency' reported here. This change is so profound that if tremor frequency depends in any way on the 'natural frequency' of the part, it can be expected to change in conformity with it.

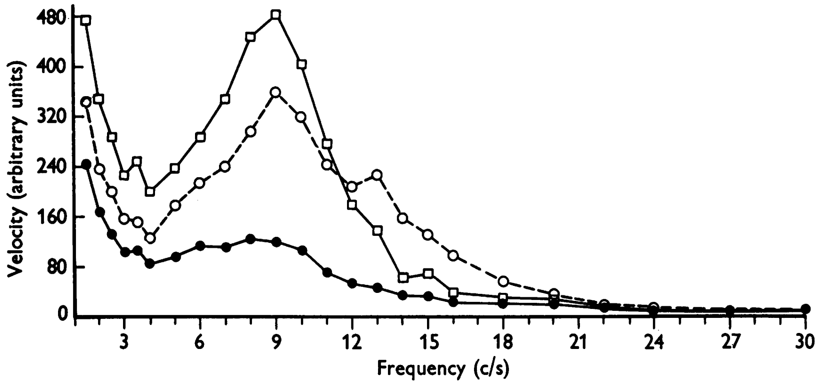

Fig. 8. Mean tremor spectra for twenty-six men with the unloaded finger ●, and with 50 g ○ and 100 g □ strapped to the terminal phalanx. Analysis of finger velocity.

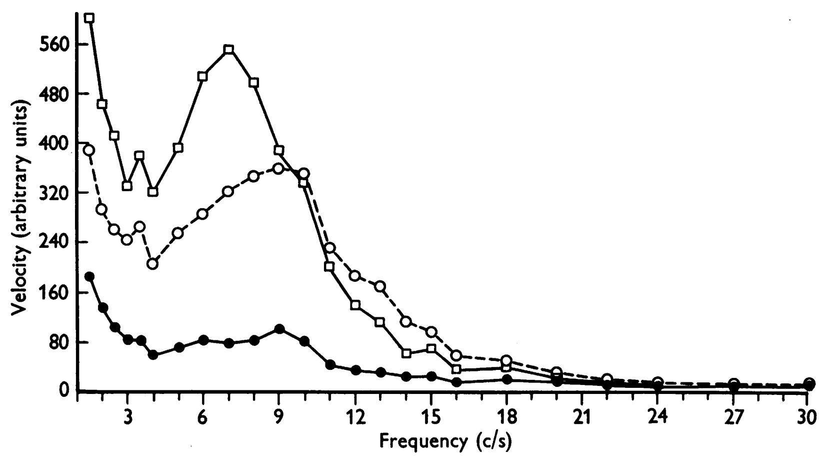

Fig. 9. Mean tremor spectra for twenty women with the unloaded finger ●, and with 50 g ○ and 100 g □ strapped to the terminal phalanx. Analysis of finger velocity.

The effect of added weights on finger tremor. The mean tremor spectra for the loaded and unloaded finger in men and women are shown in Figs. 8 and 9. In spite of the lowering of the 'natural frequency' from 27·4 to 7·6 c/s, the three tremor spectra are of substantially the same shape. The main component, from 5 to 15 c/s, is present in all three, and in the spectrum for men there is no apparent tendency for it to change its predominant frequency, though in that for women this is shifted from 9 to 7 c/s. As with the tremor of the unloaded finger in different subjects (Figs. 4, 5), this constancy of frequency is in contrast to the large change in amplitude, an effect which is rather more marked in the women than in the men. With the 100 g weight, however, there tends to be some smoothing of the contours of the spectrum, the upper frequencies (from 9 c/s) being proportionately much lower in amplitude than in the 50 g record. This is probably due to the increased inertia, and failure of the limb to 'follow' at higher frequencies.

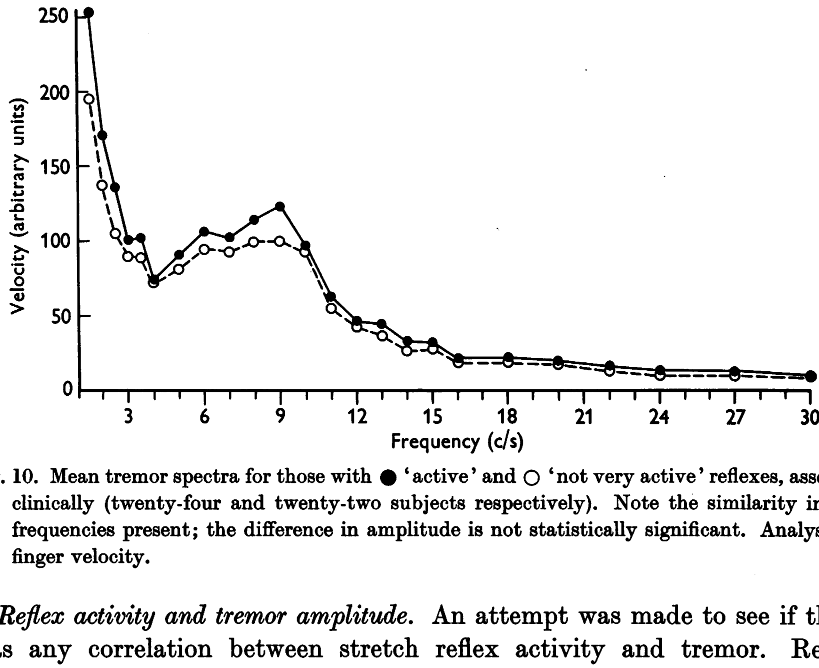

Fig. 10. Mean tremor spectra for those with ● 'active' and ○ 'not very active' reflexes, assessed clinically (twenty-four and twenty-two subjects respectively). Note the similarity in the frequencies present; the difference in amplitude is not statistically significant. Analysis of finger velocity.

Reflex activity and tremor amplitude. An attempt was made to see if there was any correlation between stretch reflex activity and tremor. Reflex activity was assessed clinically and the subjects were divided into two groups, those with active or very active reflexes (twenty-two subjects) and the rest, who had less active or absent reflexes (twenty-four subjects). The resulting frequency spectra for velocity records are shown in Fig. 10. There is no difference in the frequencies of tremor in the two groups. The slightly lower mean amplitude of tremor in those with diminished or absent tendon jerks is not statistically significant as judged by the t test ($t<1{\cdot}4$ at all frequencies; t is $2{\cdot}04$ for $P=0{\cdot}05$).

DISCUSSION

It is clear from the experimental results presented above that the frequency spectrum of the muscular forces involved in normal voluntary finger extension shows an increase in activity between 5 and 15 c/s, rising to a maximum at about 9 c/s. Such a rhythm might result from any of the four following causes:

(1) It might be due to a rhythm imposed on the motoneurones by rhythmical bursts of impulses from a source or sources higher in the nervous system, for example, from the motor cortex or brain-stem reticular formation.

(2) It might be due to some inherent rhythmical propensity of the spinal level of motor organization, either a rhythmical property of the motoneurones themselves or of the spinal system of neurones and interneurones.

(3) It might be due to some rhythmical propensity of the stretch reflex mechanism, necessitated, for example, by the delay between a stretch stimulus and the development of the resulting corrective muscular forces. The duration of this delay is probably of the right order to account for the observed frequency of tremor.

(4) The purely mechanical resonant properties of the moving parts—finger, tendons and muscles—must play some part in modifying the amplitude of movement resulting from rhythmical muscular forces of any particular frequency. These properties might, however, be anything from dominant to negligible relative to one or more of the first three factors.

Schäfer (1886), using a tambour method of recording muscular contractions, claimed to show that a 10/sec rhythm is present in muscular contraction whether the contraction is brought about by voluntarily or by stimulation of the motor cortex, of the corona radiata, or of the cut end of the spinal cord. These findings, especially if confirmed by the use of more satisfactory recording technique, would seem to negate the prepotence of rhythmical sources above the spinal level. Lindqvist (1941) has shown that whereas overbreathing markedly slows the alpha rhythm of the cerebral cortex, it has no parallel effect on the frequency of finger tremor.

There have been considerable differences among previous writers concerning the effect of loading a limb on its tremor. Griffiths (1888) reported an increase in frequency; Bloch & Busquet (1904), and Bishop, Clare & Price (1948) found that tremor rates were unaltered by loading, and Kuhnke (1952) has recently reported a decrease in frequency. The present results show that increased activity between 5 and 15 c/s, with a maximum around nine cycles, is present regardless of the load on the finger. The fact that loading caused a profound change in the mechanical properties of the part, as evidenced by the change in the frequency of the die-away oscillations following a sharp tap, while tremor frequencies remain comparatively unchanged, indicates that mechanical resonance is not of decisive importance in determining tremor frequencies.

The only factors remaining to explain the increase in amplitude between 5 and 15 c/s are therefore an inherent spinal rhythmicity, or the properties of the stretch reflex. The fact that tremor amplitude is not related to the clinical briskness of the tendon jerks in normal individuals does not exclude the stretch reflex as the source of the rhythm. Indeed, in tabetic patients with partial de-afferentation the normal increase in activity between 5 and 15 c/s with a maximum at 9 c/s, is often absent (Halliday & Redfearn, unpublished). In view of the known relationship of clonus with the stretch reflex, it is interesting that Strughold (1927) was able to alter the frequency of patellar clonus in the decerebrate cat by varying the moment of inertia of the limb with a 20 or 40 g weight attached to the leg 8 cm from the knee-joint. However, a four-fold increase in the moment of inertia affected a reduction in frequency only from the initial 11–12/sec to 9/sec.

SUMMARY

1. Finger tremor has been recorded in forty-six healthy subjects, twenty-six men and twenty women, by a system free from inertia, and the frequencies present between 1·5 and 30 c/s have been determined by the use of an automatic low-frequency analyser.

2. All subjects showed a more or less constant spectrum of tremor frequencies between 5 and 15 c/s. The amplitude of tremor varied widely, however, both from individual to individual and, to a less extent, in one individual from one time to another.

3. Tremor rates computed by measuring the peak frequency (that of greatest amplitude) are liable to be misleading unless it is specified whether displacement, velocity or acceleration are being recorded. The former will give a lower peak reading than its two derivatives. In terms of a force spectrum it can be said that energy is being fed into the system between 5 and 15 c/s with a peak amplitude at 9–10 c/s.

4. Tremor frequency is virtually unaffected by loading the finger with 50 or 100 g, except for some failure to follow at higher frequencies with the larger weight. This is in marked contrast to the amplitude, which increases greatly with increasing load. As the added weights profoundly affect the mechanical properties of the finger (reducing the frequency of the die-away oscillations following a sharp tap from 27 to 7 c/s), but do not alter tremor rate, it can be concluded that tremor rates are virtually independent of the mechanical properties of the limb.

5. Stretch reflex activity was assessed clinically, and tremor amplitude and frequency were compared in two groups whose tendon jerks were 'active' and 'not very active' respectively. There was no difference in tremor frequencies and no significant difference in tremor amplitude between the two groups.

6. These results do not necessarily imply that the tremor rhythm cannot be due to servo instability in the stretch reflex arc, as such a mechanism would be expected to be relatively independent of loading and of small changes in loop gain.

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