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Intention tremor—a method of measurement

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SYNOPSIS A method of measuring and analysing intention tremor using a linear accelerometer is described. Reasons are given for measuring this particular parameter of the tremor, for using this specific energy conversion device, and for employing the particular form of analysis. A comparison of the numerical values obtained for the amount of tremor activity, compared with a corresponding clinical grading, is made for 30 patients with intention tremor due to a variety of pathological causes. It is shown that the method gives clear correlation with the clinical assessments, although certain discrepancies are noted, and their importance discussed.

Tremor may be defined as a series of involuntary, relatively rhythmic, purposeless, oscillatory movements involving a part or parts of the body moved by skeletal muscle (Brumlik and Yap, 1970). When tremor occurs during voluntary movement it may be called 'intentional', to distinguish this form of abnormal movement from either tremor of a limb at rest, often called static tremor, or tremor of a limb extended against gravity, often called anti-gravity tremor. It has been stated that a study of involuntary movements presents a difficult but challenging task (Liversedge, 1962) but reports of attempts to treat intention tremor have recently shown a small measure of success (Cooper, 1965; Hewer *et al.*, 1972). Objective evaluation of progress and treatment of involuntary movements has proved a particularly difficult problem. Thus, many methods exist to measure tremor in the resting limb, but very few of these have been applied to intention tremor. The problem of measurement and analysis of intention tremor is complicated because of the three-dimensional aspects of movement of a limb in space, because of the rapidity of the positional changes, and because of related movements of other parts of the body. In addition, there are marked variations in the severity of the disability with repetition of the task.

Tracings of simple movements on a revolving drum have been used to provide a graphic representation of intention tremor due to lesions of the cerebellum (Holmes, 1939). Analysis of motion pictures has been used in an attempt to obtain a better representation of time and space (Dierssen *et al.*, 1961). These methods were laborious to analyse and were not easily repeated for statistical appraisal. Indirect methods of measuring intention tremor have also been developed. Chase and his colleagues in 1965, used a linear rotary motion potentiometer to generate a signal proportional to the movement of the subject's finger in a vertical plane. The subject was then required to maintain his finger at a reference point in space while visual displays were presented on a cathode ray tube to give information about finger position and reference position. This compensatory tracking task provided quantitative data about control of voluntary movement. Such data provide only indirect information, for the limb is not free to move in space, and the task cannot readily be compared with the clinical examination, nor with the subject's usual performance of everyday tasks.

More recent technological advances have provided transducers which may be used to produce an immediate graphical representation of tremor. However, most published reports refer to the rhythmic tremor at rest, or on action against gravity, of patients with Parkinson's disease, or of normal subjects (Brumlik, 1962; Yap and Boshes, 1967). The present study is an attempt to investigate the use of a linear accelerometer to graph intention tremor, and to evaluate a method of analysing these traces to produce quantifiable

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data. A preliminary study with a small group of patients has already been reported (Morgan *et al.*, 1972), and this work has since been extended to include a larger group of patients with intention tremor of varying severity. Assessment of disability enables various methods of treatment to be compared objectively, and the development of this particular method forms part of a project investigating possible means of reducing disability due to intention tremor.

METHODS

PATIENTS Clinical assessments and recordings were made on a series of 30 patients who exhibited tremor during the performance of voluntary movements. The clinical diagnoses for these 30 patients were as follows, with the numbers of patients given in parentheses:

Multiple sclerosis (10), cerebellar degeneration of unknown cause (five), idiopathic or essential tremor (five), Friedreich's ataxia (two), cerebrovascular disease affecting the brain-stem territory (two), congenital lesions affecting the basal ganglia (two), traumatic lesions affecting the brain-stem territory and cerebellum (two), tumour of the cerebellum (one), and Parkinson's disease (one). The ages of the patients in the series ranged from 14 to 65 years, with a mean age of 41 years; there were 17 males and 13 females. Eleven patients had mild tremor, nine moderate, six severe, and four very severe tremor of their dominant hand, as judged by clinical assessments and simple rating tests.

TREMOR MEASUREMENTS *Clinical assessments* Tasks of manual dexterity, such as the finger/nose and pronation/supination tests, as well as a series of maze and pattern drawing tests were employed. A four point rating scale of tremor severity was based on a visual estimate of severity of the tremor, where a score of 1 indicated mild tremor, 2 moderate, 3 severe, and 4 very severe tremor. Grades 3 and 4 indicated tremor severe enough to cause interference with the patient's daily tasks such as dressing, eating, and drinking. No patient exhibited marked weakness of the dominant limb, and only one patient had loss of position sense in the fingers.

Recording procedure Tremor was recorded with a linear accelerometer (M.E.M. Electro Mechanisms Ltd, Slough), weighing 25 *g*, size 3.0 × 2.1 × 1.1 cm, with an acceleration range of plus or minus 6 *g*. The transducer was strapped tightly to the dorsum of the hand at the base of the index finger. Its active axis was sensitive to movements in a horizontal plane, which was at right angles to the direction of movement of a simple motor task performed by the patient.

The task was a simple one, consisting of horizontal movement of the pronated limb, from the shoulder to a target button placed at a suitably adjusted arm range directly in front of the patient's shoulder. The patient was instructed to move his arm slowly and steadily towards the target button, taking approximately four seconds for the performance of the task. Practice with a stop clock was undertaken until this could be achieved on most attempts. During recording, only the attempts which took approximately four seconds were retained for analysis. In order to minimize the effect of fatigue, a two minute rest period was allowed between each trial procedure. The output from the accelerometer was recorded, using an Elema-Schonander Mingograph. A standard amplifier gain, such that an output of 1 *g* gave 1.5 cm deflection of the recorder, was used throughout the experiments.

The apparatus was connected on line to a Linc 8 computer and the data were sampled at a rate of 128 points per second. A known calibration signal of 1 *g* was sampled before each series of recordings, and the signal displayed on the computer oscilloscope was normalized to produce a standard deflection. This procedure ensured that all experimental data were comparable for each patient.

Pressure on the target button caused sampling to stop and the accelerometer output obtained during the immediately preceding four seconds was displayed on the computer oscilloscope screen. The test

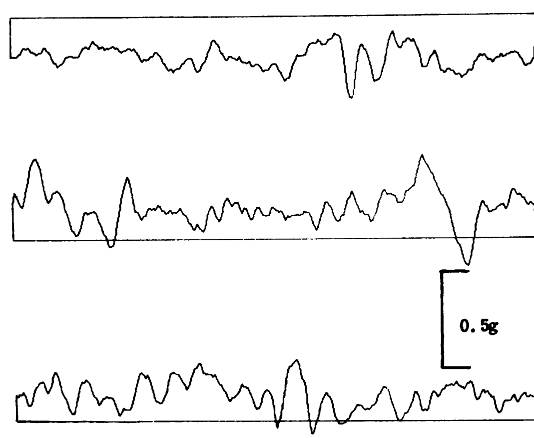

FIG. 1 *Three accelerometer recordings from a patient with multiple sclerosis. The duration of each trace is 2 s and the calibration signal for the accelerometer is shown.*

data could then be stored on computer tape for later analysis.

Analysis of tremor traces The stored data contained steady level and low frequency components, due to the acceleration and deceleration of the limb towards the target, and accentuated by any minor rotation of the accelerometer due to rotation of the limb. These frequencies, below 2 Hz, were considered to be unwanted artefact. To remove these, the stored data were subjected to a frequency analysis. The programme which was written to perform this procedure made use of a Fourier analysis of the waveform. The component frequencies from 0 to 64 Hz, in $\frac{1}{4}$ Hz steps, were displayed on a computer screen as a frequency power spectrum. Each spectrum displayed could be subjected to certain modifications by means of the control programme. Frequencies between 0 and 2 Hz were erased from the traces, and the reconstituted wave form was then compared with the original trace. Any magnification factor due to the analysis could be corrected, and the trace was then balanced about a mean, rectified and integrated. From this procedure it was therefore possible to obtain a numerical value which represented the amount of tremor activity in arbitrary units for each four seconds test run. A series of 10 tests was recorded for each patient.

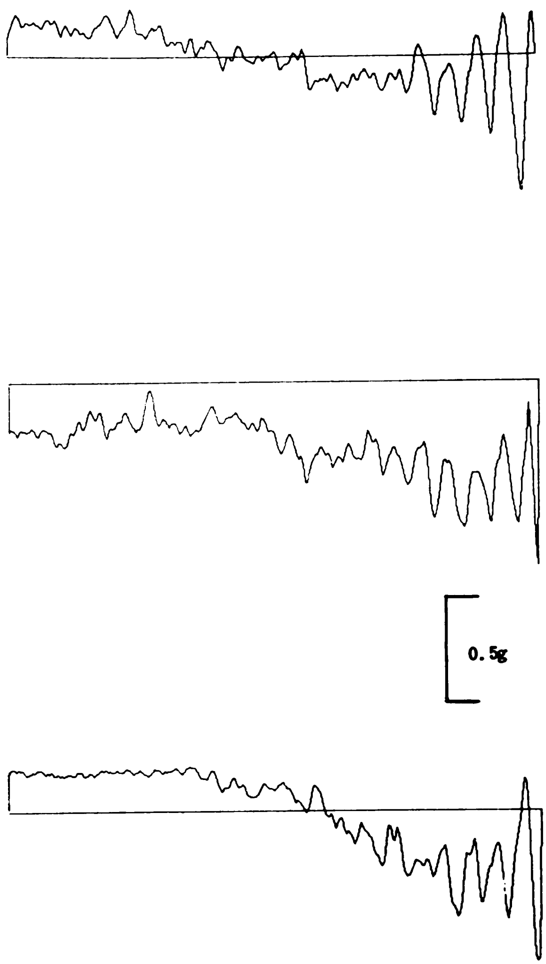

FIG. 2 *Three accelerometer recordings from a second patient with multiple sclerosis. The duration of each trace is 2 s, and shows the hand movement recorded during the terminal 2 s before a target was struck. Terminal accentuation of the tremor can be seen.*

RESULTS

Representative tremor traces from a patient with multiple sclerosis can be seen in Fig. 1. Although there was considerable variation in the amount of tremor in different traces from

TABLE

CLINICAL ASSESSMENT COMPARED WITH MEASUREMENT OF TREMOR SEVERITY FOR 30 PATIENTS

*Clinical ratings of tremor**	*Tremor measurements in arbitrary units (mean of 10 values ± standard deviation)*
1	63 ± 2
1	94 ± 17
1	95 ± 23
1	105 ± 41
1	113 ± 38
1	116 ± 52
1	125 ± 23
1	145 ± 50
1	157 ± 58
1	176 ± 63
1	122 ± 38
2	132 ± 42
2	138 ± 35
2	173 ± 60
2	182 ± 48
2	198 ± 47
2	221 ± 52
2	238 ± 61
2	281 ± 87
2	210 ± 45
3	262 ± 71
3	319 ± 108
3	387 ± 86
3	444 ± 108
3	484 ± 206
3	499 ± 51
4	502 ± 213
4	911 ± 221
4	946 ± 173
4	1 175 ± 252

* 1—mild, 2—moderate, 3—severe, 4—very severe.

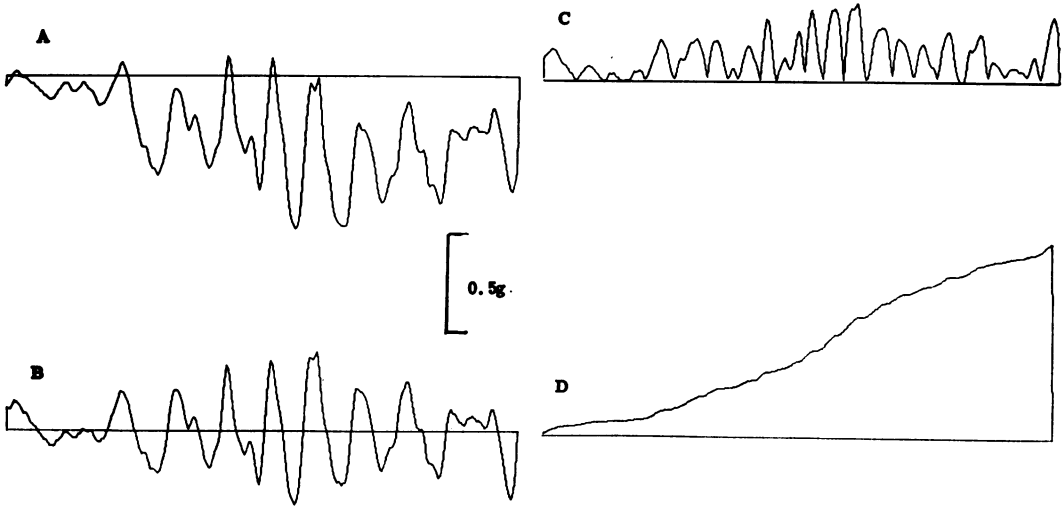

FIG. 3 *Analysis of a representative trace of 2 s duration.* A: *the original trace.* B: *the trace balanced about a mean after removal of low frequencies (2 Hz and below).* C: *the effect of rectification.* D: *integration.*

the same subject, a similar frequency pattern could sometimes be detected in several samples from the same patient. The presence of a terminal accentuation in the tremor could be readily detected (Fig. 2).

The results of the various processes and analysis on a representative trace can be seen in Fig. 3. The Table lists the mean of 10 tremor measurements, and the appropriate clinical grades of tremor severity for each patient. The ratio of the standard deviation to the mean value, expressed as a percentage—that is, the coefficient of variation—gave an average value of 28%, with a range from 3 to 44%. Some overlap is apparent between the groups, but the values for tremor activity obtained by accelerometer measurements correlated reasonably well with the grading scales obtained by clinical assessment. Student's t test, taking square roots to normalize the data, gave a significant difference between each of the four populations. Results obtained were $t=4.195$, $P<0.001$ for groups 1 and 2; $t=5.318$, $P<0.001$ for groups 2 and 3; and $t=3.481$, $P<0.01$ for groups 3 and 4.

DISCUSSION

This study has demonstrated that sufficient correlation exists between the clinical assessments of tremor severity and the respective accelerometer measurements to justify the use of this method for quantifying intention tremor. The choice of transducer, and the method of analysis, resulted from a consideration of earlier studies by workers who had investigated the so-called static and antigravity tremors, as little published work exists on the measurement of intention tremor. Randall and Stiles (1964) commented that it was impossible to establish the 'best method of sensing finger tremors', and these authors felt that the choice depended upon a method which provided the maximum relevant with the minimum irrelevant information. They added that no one had established which of the possible parameters were most relevant, and hence the choice was not limited but could be either displacement, velocity, acceleration, or isometric force.

The choice of acceleration as a measured variable results from practical considerations. Marshall and Walsh (1956) pointed out some of the advantages of measuring acceleration rather than displacement. They stated that according to Newton's second law, the force put into a limb will be reflected in its acceleration. Secondly, graphic records of acceleration reveal smaller discontinuities during the course of a movement than would be shown by displacement recordings, and, thirdly, the technique is simple to use. Acceleration measurements respond to moderately fast changes, and it was shown by Randall and Stiles (1964) that the spectra show better reproducibility than those of displacement or isometric force. These authors also noted that, while mathematical transformation was theoretically possible between displacement, velocity, and acceleration, in practice these procedures are not ideal.

In recent years commercial transducers have been used in studies of physiological tremor and tremor of Parkinsonism. Various energy conversion devices have been developed, such as piezoelectric crystals and variable reluctance transducers. The disadvantages of the piezoelectric transducers were found to be, firstly, that the output required a constant change of acceleration, and, secondly, that the high resistance of these materials made them sensitive to electrical radiation from other equipment, giving rise to interference signals (Rohracher, 1962; Van Buskirk *et al.*, 1966). A double diode accelerometer used by Marshall and Walsh (1956) was also criticized as being relatively insensitive to low frequencies and not responding solely to linear acceleration, although it was thought to be accurate for the very small excursions of physiological tremor. Variable reluctance accelerometers appear to be free from these criticisms, and have been used by several workers in recent years—for example, Yap and Boshes (1967) and Brumlik and Yap (1970).

Quantitative analysis of the resulting traces has been made easier by modern equipment such as computers. Randall and Metzger (1963) and Randall (1967) produced data by finding continuous estimates of the variance of the tremor. Marsden and his colleagues in 1967 and again in 1969, used the analogue integration of the output of the angular accelerometer for frequency analysis. Similarly, Cowell *et al.* (1965) produced quantified data which were based on integration of the tremor traces. These authors investigated patients with tremor of Parkinsonism but the method was not applied to patients with intention tremor.

It is well known that the degree of tremor may not only vary from moment to moment, but also alter with the conditions under which the test is performed. The problem of variability in any study of intention tremor is even greater than in studies on tremor of a limb at rest. For this reason it is particularly important that the task be a simple one which can be easily repeated on many occasions, and that some form of quantifiable result can be subjected later to statistical appraisal. Both these criteria are met in the method described. Any objective study of intention tremor thus presents certain difficulties in common with those encountered in measurements of static and antigravity tremors, but in addition it poses the particular problem of distinguishing task movement from superimposed tremor frequencies. The slow activity considered to arise from task movement was arbitrarily set as that below 2 Hz. This value was determined from analysis of traces during the initial pilot study, but a similar level was used by Ackmann *et al.* (1969) to exclude all voluntary movement, in their investigations into tremor in Parkinsonism. The use of a Linc 8 computer in the present study enabled a rapid frequency analysis to be performed on the tremor traces, and the data manipulating programme enabled variation in the procedures used for the analysis, during the early pilot studies.

The overall correlation of clinical disability with objective data was good, but some anomalous results were noted. Patients with a marked rhythmic tremor of moderately high amplitude could often use the affected limb more easily than other patients with an irregular, lower amplitude tremor. Here, of course, the pathological aetiology and the diagnosis are relevant. For instance, one patient with an essential tremor at 5 to 6 Hz could control one hand by steadying it with the other hand, but another patient with a low amplitude intention tremor due to multiple sclerosis was not able to improve his performance in this way. The tremor index for the former patient was found to be higher than for the latter patient, although the degree of social disability experienced by the former was less marked. Nevertheless, such discrepancies were the exception, and in the large majority of cases the tremor index provided a very useful measurement, which could be easily repeated on several occasions for statistical studies.

REFERENCES

Ackmann, J. J., Sances, A., Jr, and Larson, S. J. (1969). Automated analysis of Parkinson tremor. *Proceedings of the International Meeting on Engineering in Medicine and Biology*. (Personal communication.)

Brumlik, J. (1962). On the nature of normal tremor. *Neurology (Minneap.)*, **12**, 159–179.

Brumlik, J., and Yap, C. B. (1970). *Normal Tremor; a Comparative Study*. Thomas: Springfield, Ill.

Chase, R. A., Cullen, J. K., Jr, Sullivan, S. A., and Ommaya, A. K. (1965). Modification of intention tremor in man. *Nature*, **206**, 485–487.

Cooper, I. S. (1965). Clinical and physiologic implications of thalamic surgery for disorders of sensory communication. Part 2. Intention tremor, dystonia, Wilson's disease and torticollis. *Journal of the Neurological Sciences*, **2**, 520–553.

Cowell, T. K., Marsden, C. D., and Owen, D. A. L. (1965). Objective measurement of Parkinsonian tremor. *Lancet*, **2**, 1278–1279.

Dierssen, G., Lorenc, M., and Spitaleri, R. M. (1961). A new method for graphic study of human movements. *Neurology (Minneap.)*, **11**, 610–618.

Hewer, R. L., Cooper, R., and Morgan, M. H. (1972). An investigation into the value of treating intention tremor by weighting the affected limb. *Brain*, **95**, 579–590.

Holmes, G. (1939). The cerebellum of man. *Brain*, **62**, 1–30.

Liversedge, L. A. (1962). Involuntary movements—a clinical review. In *Modern Trends in Neurology*, vol. 3, pp. 57–74. Edited by D. Williams. Butterworths: London.

Marsden, C. D., Foley, T. H., Owen, D. A. L., and McAllister, R. G. (1967). Peripheral β-adrenergic receptors concerned with tremor. *Clinical Science*, **33**, 53–65.

Marsden, C. D., Meadows, J. C., Lange, G. W., and Watson, R. S. (1969). Variations in human physiological finger tremor, with particular reference to changes with age. *Electroencephalography and Clinical Neurophysiology*, **27**, 169–178.

Marshall, J., and Walsh, E. G. (1956). Physiological tremor. *Journal of Neurology, Neurosurgery, and Psychiatry*, **19**, 260–267.

Morgan, M. H., Hewer, R. L., and Cooper, R. (1972). A method of recording and analysing intention tremor. *Brain*, **95**, 573–578.

Randall, J. E., and Metzger, J. M. (1963). Variance as a measure of tremor amplitude. *Journal of Applied Physiology*, **18**, 440–441.

Randall, J. E., and Stiles, R. N. (1964). Power spectral analysis of finger acceleration tremor. *Journal of Applied Physiology*, **19**, 357–360.

Randall, J. E. (1967). Analog and digital computers in the study of physiologic tremor. *Archives of Physical Medicine and Rehabilitation*, **48**, 463–466.

Rohracher, H. (1962). Permanente rhythmische Mikrobewegungen des Warmblüter-Organismus ('Mikrovibration'). *Naturwissenschaften*, **49**, 145–150.

Van Buskirk, C., Wolbarsht, M. L., and Stecher, K., Jr (1966). The nonnervous causes of normal physiologic tremor. *Neurology (Minneap.)*, **16**, 217–220.

Yap, C. B., and Boshes, B. (1967). The frequency and pattern of normal tremor. *Electroencephalography and Clinical Neurophysiology*, **22**, 197–203.