Journal of Neuroscience Methods, 32 (1990) 193–198
Elsevier

NSM 01070

Quantification of tremor with a digitizing tablet

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(Received 27 September 1989)
(Revised version received 5 January 1990)
(Accepted 29 January 1990)

Key words: Tremor; Handwriting; Drawing; Digitizing tablet; Personal computer

Handwriting and drawing are commonly employed in the clinical assessment of tremor. These tasks have been quantified heretofore by subjective rating schemes, which are incapable of providing precise measures of the amplitude and frequency of tremor. A commercially-available digitizing tablet and personal computer can be interfaced so as to reliably record any pathologic tremor that is induced by writing or drawing. Numerical differentiation and spectral analysis can be used to conveniently quantify the amplitude and frequency of tremor. However, digitizing tablets lack sufficient sensitivity to measure physiologic tremor.

Introduction

Specimens of handwriting and Archimedes spirals are commonly used in the evaluation of patients with pathologic tremor. However, quantification of these data has been limited to subjective assessments of clarity and smoothness (Koller et al., 1986). Precise measures of tremor amplitude and frequency are not possible with these methods.

Recent advances in electronic technology have provided many useful tools for the quantification of tremor. Accelerometry is the most popular method because of its sensitivity and versatility (Budd, 1984; Gilstrap, 1984). However, the one-dimensional accelerometers that are most commonly employed provide only a partial assessment of tremor amplitude. When measuring tremor of a limb segment, one must contend with translational movement in three dimensions (e.g., X, Y, and Z) and rotational movement about the instantaneous axis of rotation (Winter, 1979). To measure all components of tremor, at least 6 one-dimensional accelerometers are needed (Padgaonkar et al., 1975; Gilbert et al., 1984). Consequently, a one-dimensional accelerometer mounted on a hand or pen cannot accurately measure the net amplitude of tremor.

When evaluating drawings and handwriting, the complex kinematics of limb motion usually are not the principal concern. Instead, most clinicians are primarily interested in quantifying (1) the size and shape of the letters and drawings, and (2) the amplitude and frequency of superimposed tremor. Both objectives can be accomplished with one of several commercially-available digitizing tablets, interfaced with a personal computer.

Methods

Digitizing tablets

More than 30 digitizing tablets are available for use with IBM-compatible personal computers. Many of these tablets were reviewed by Stanton

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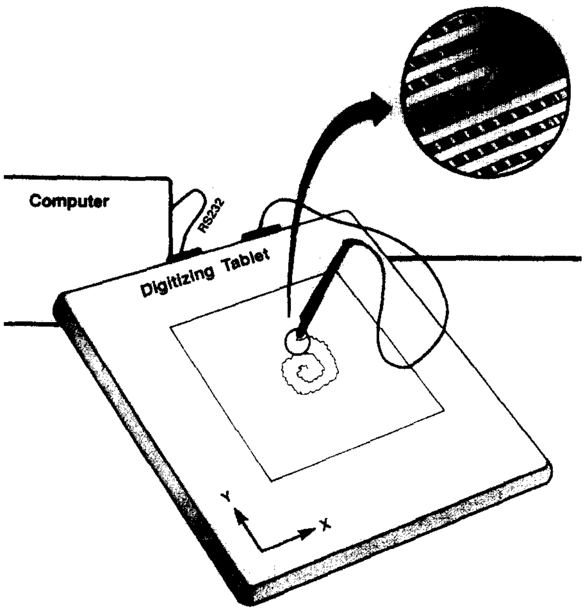

Fig. 1. Most digitizing tablets contain a fine grid of horizontal and vertical wires that are activated by an electromagnetic field from a stylus or puck. These tablets are connected to an IBM-compatible computer with RS-232 serial cable.

(1987) and by Diehl and Apiki (1989). Beneath the writing surface of most tablets is a fine wire grid comprised of evenly-spaced horizontal and vertical wires (Fig. 1). A stylus (pen) or puck emits an electromagnetic field that excites neighboring horizontal and vertical wires. The tablet computes the horizontal (X) and vertical (Y) coordinates of the stylus or puck by determining the horizontal and vertical wires that are most strongly excited.

The maximum rate of digitization for most tablets is 200 samples per second (Diehl and Apiki, 1989). Nearly all tablets interface with the computer through an RS-232 serial port. The actual rate of data transmission to the computer (i.e., the sampling rate) is determined by the tablet's hardware, by the baud rate of communication between the computer and tablet, and by the format of data transmission. The highest speed of data transmission (200 X-Y pairs per second) for our tablet required a baud rate of 19 200. However, the maximum baud rate for our computer (and most others in current use) was 9600. At this rate of data transmission, the speed of digitization for our tablet was 169 per second.

Most tablets can transmit data in ASCII or packed binary format. The packed binary format is most efficient and is necessary for the highest rates of data transmission. Therefore, the packed binary format was used in the development of our software.

Digitizing tablets have finite resolutions that vary from 78.7 to 787 lines per cm (Diehl and Apiki, 1989). The maximum resolution is determined by the number of wires in the X-Y grid and by the format that is used for transmission of data to the computer. Consequently, many tablets have more than one resolution. For our 30.5×30.5 cm tablet, the packed binary format provided a resolution of 78.7 lines per cm. In other words, a 1-cm line contained 78 equally-spaced X-Y data pairs, and the stylus or puck moved 0.127 mm before the tablet reported a new position. The accuracy of our tablet was ± 0.254 mm, and in general, the reported accuracy for most tablets is not as good as the reported resolution (Diehl and Apiki, 1989). Therefore, the lowest one or two bits of each X and Y value are noise from the tablet.

A subroutine (procedure) to receive data from our tablet was written in Microsoft Assembler, as outlined by Jourdain (1986). This procedure was called from a main program that was written in Microsoft Quick Basic, but it could also be called from programs written in Fortran, Pascal, or C. The main program moved the packed binary data from a specified memory segment into arrays of X and Y data. Once the data were in suitable arrays, they could be graphically displayed and subjected to various methods of quantitative analysis.

Estimates of velocity and acceleration were obtained with 9-point quadratic splines (Savitzky and Golay, 1964). These splines produced accurate differentiation with the added advantage of attenuating signals at frequencies above 13 Hz. The X and Y components of tremor in the position, velocity, and acceleration data were then analyzed separately by fast Fourier transformation. The X and Y tremor amplitudes were computed by taking the square root of the area under the X and Y spectral peaks, respectively, and the resultant (net) tremor amplitude was computed by

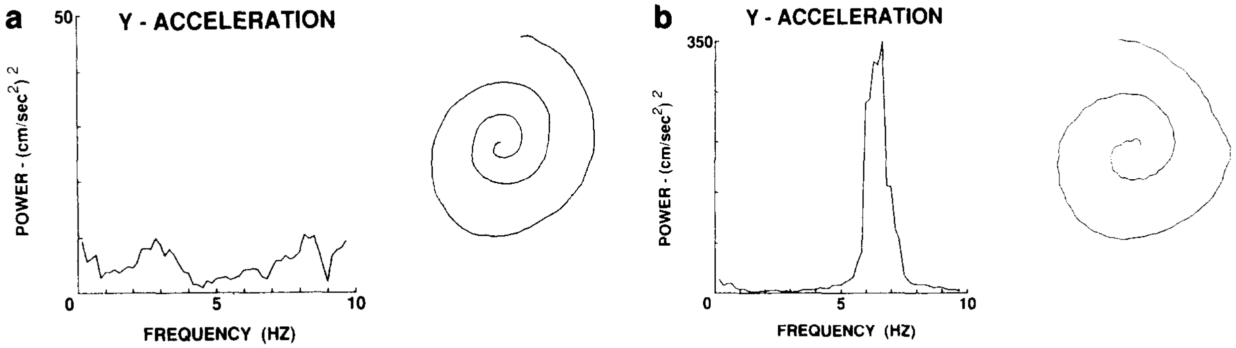

Fig. 2. These Archimedes spirals were drawn by a normal man (a) and a man with mild essential tremor (b). Power spectra of acceleration in the Y direction are shown. For normal subjects, the spectral activity in the frequency range of physiologic tremor (6–12 Hz) was not distinguishable from noise. By contrast, even mild essential tremor produced a consistent spectral peak at the frequency of tremor.

taking the square root of the sum of the areas under the X and Y spectral peaks. Our sampling frequency of 169 per second was more than 10 times the highest frequencies of physiologic and pathologic hand tremor (Elble and Randall, 1978; Elble, 1986) and far exceeded the 0–6-Hz frequency content of handwriting and drawing (Hollerbach, 1981). Therefore, spectral aliasing was not a problem in our work.

Results

To test our tablet, 6 normal adults and 12 patients with essential tremor were asked to copy an Archimedes spiral and to write "because" and a series of cursive "e" on a piece of 21.6 × 27.9-cm paper. Examples of Archimedes spirals from a normal subject and from a patient with mild essential tremor are shown in Fig. 2a and b. Physiologic hand tremor has a peak-to-peak amplitude of less than 0.5 mm (Elble 1986), and given the accuracy and resolution of our tablet, it is understandable that physiologic tremor could not be measured with our tablet (Fig. 2a). By contrast, we found that even mild pathologic tremor (peak-to-peak amplitudes of 1.0 mm or greater) was consistently recorded (Fig. 2b).

To quantitatively estimate the digitization noise of our tablet, precise lines were carefully drawn with a ruler or French curve. Numerical differentiation was performed, followed by spectral analysis. In general, the digitization noise produced broad-spectrum activity (Fig. 3) with an amplitude that was far below that of mild pathologic tremor (Fig. 2b). Specifically, the mean peak-to-peak amplitudes of displacement, velocity, and acceleration noise were less than 0.3 mm, 0.7 cm/s, and 7 cm/s^2, respectively.

Even in patients with advanced tremor, the low-frequency volitional displacements of writing and drawing typically dominated the digitized time series of X-Y data (Fig. 4). Because tremor has a higher frequency than drawing and writing, numerical differentiation accentuated the tremor

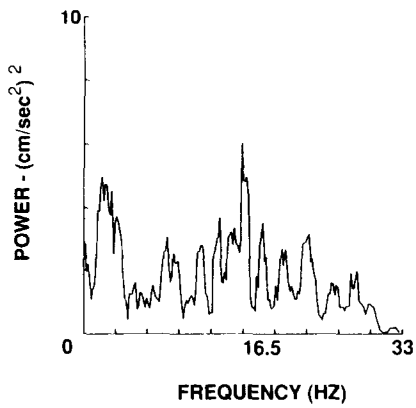

Fig. 3. Spectral analysis was performed on the Y-acceleration of a diagonal line that was drawn with a stylus and ruler. Only broad-spectrum noise was found in the frequency range of tremor. This noise was much less than spectral activity of mild pathologic tremor (Fig. 2b) but was comparable to the spectral activity of normal drawing (Fig. 2a).

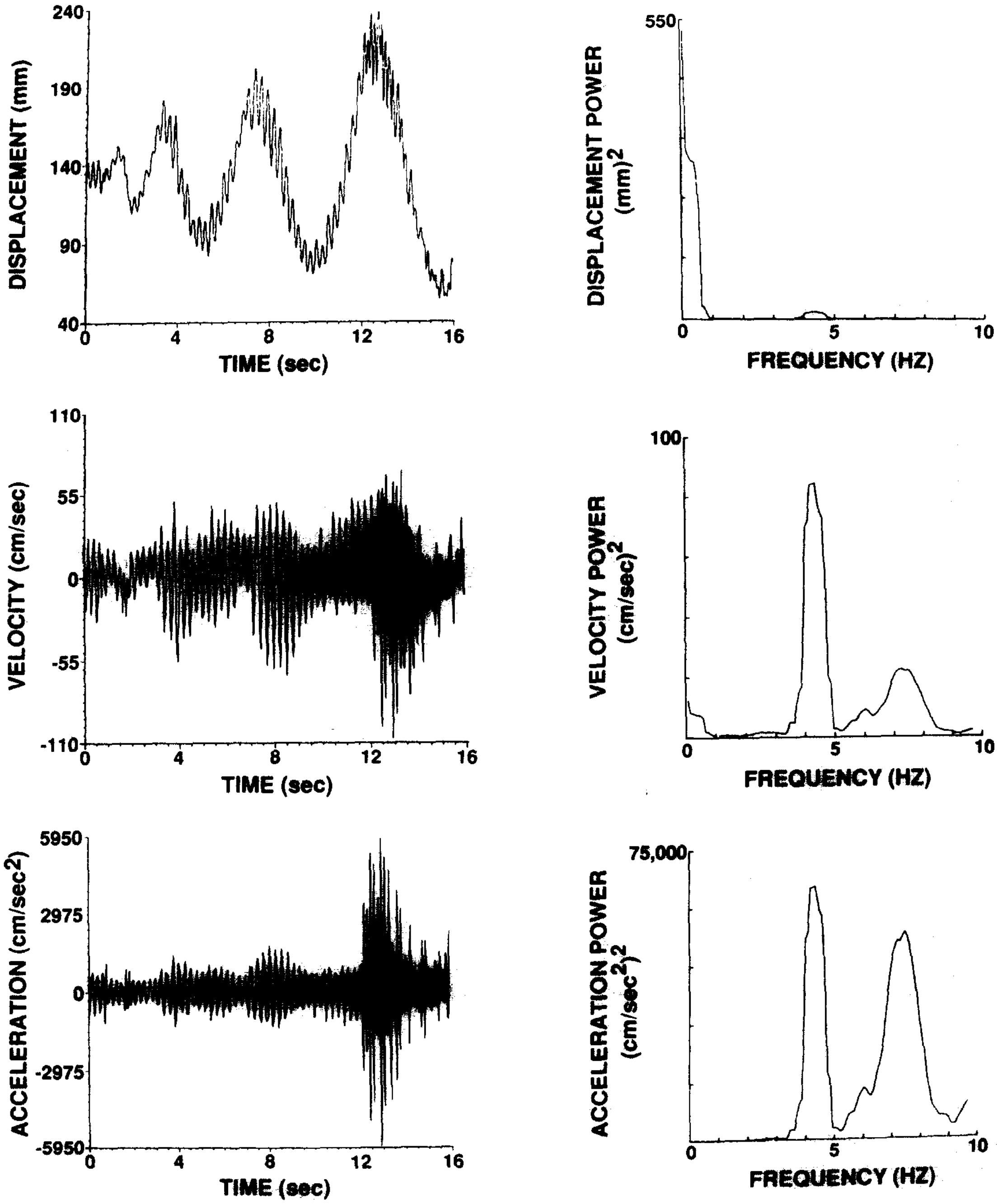

Fig. 4. The Y-components of displacement, velocity, and acceleration shown for a patient with advanced essential tremor who drew an Archimedes spiral. Corresponding power spectra are also shown. The low-frequency voluntary movement of the spiral dominates the displacement. Numerical differentiation accentuates the tremor, in proportion to its frequency. Toward the end of the drawing, the frequency of the tremor spontaneously increased, resulting in further accentuation of tremor.

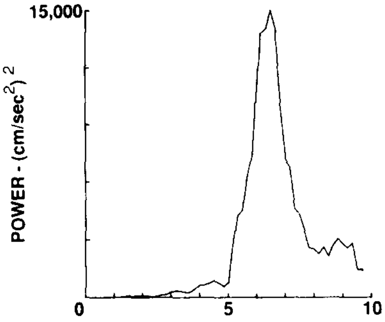

Fig. 5. An example of "because" written by a patient with advanced essential tremor. Spectral analysis of X-acceleration revealed a prominent tremor spectral peak.

in proportion to its frequency. Power spectra of differentiated signals therefore contained tremor spectral peaks that were more easily distinguished from the spectral activity of volitional movement (Figs. 4 and 5).

Discussion

This method of tremor analysis has two clear advantages over the subjective rating scales that are commonly employed in the clinical analysis of tremor. First, this method provides an objective, quantitative measure of tremor amplitude and is therefore more sensitive to small changes in tremor amplitude that could be missed by clinical scales that simply rate tremor as normal, mild, moderate, or severe. The increased sensitivity and objectivity of tablet analysis should be particularly useful in evaluating an experimental therapy that is expected to produce only modest changes in tremor amplitude. Second, analysis of tablet data provides a measure of tremor frequency. Tremor frequency is of great interest to clinicians and researchers (Elble, 1986) but is not measurable by clinical inspection of writing and drawing.

A digitizing tablet is less sensitive and less accurate than the miniature accelerometers that are commonly employed in the analysis of tremor. However, a digitizing tablet provides an efficient and relatively inexpensive method of quantifying tremor during writing and drawing, two tasks that are routinely employed in the clinical assessment of tremor. Digitizing tablets also cost less than most accelerometers and do not require additional amplifiers and analog-to-digital converters for signal processing.

The practical clinical limitations of these tablets are related to their accuracy and resolution. Sampling speed is adequate for all forms of tremor in the upper extremities. The reported accuracies and resolutions are fine for their intended use in computer graphics (Diehl and Apiki, 1989), and they are sufficient for measuring pathologic tremor. Unfortunately, existing tablets are incapable of measuring physiologic tremor. However, improved accuracy and resolution may be forthcoming as tablet technology continues to advance.

Acknowledgements

This work was supported by grant NS20973 from the National Institute of Neurological Disorders and Stroke and by Biomedical Research Grant S07RR05843 from the National Institutes of Health. Portions of this work were presented at the 1989 annual meeting of the American Academy of Neurology (Elble and Higgins, 1989). The authors are indebted to Constance Higgins for her help with data analysis.

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