A comparative study of bilateral hand tremor : during posture and voluntary motion
by Malcolm Robert Macaulay

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education
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Abstract:

A study was done to compare bilateral tremor of the hand during two different tremor provoking conditions, postural tremor (PT) and movement tremor (PAT). Specific tremor parameters quantified were, the coherence between wrist extensor e.m.g.s and the tremorous motion, the coherence between wrist extensor e.m.g.s of the two forearms, and the frequency and amplitude of tremor in the dominant and non-dominant hand.

Thirteen subjects participated. All subjects had bipolar electrodes placed over the belly of the extensor digitorum and the flexor digitorum superficialis on each forearm. A lightweight accelerometer was placed just proximal to the DIPjoint on the third phalanx of each hand.

During PT the subject extended the wrist to zero degrees of flexion-extension and maintained the position against the force of gravity for two minutes. During PAT the subject flexed and extended the wrist in time with a visually displayed 0.25 Hz sine wave. PAT was analyzed as the subject began a flexion movement after being fully extended.

The results showed differences and similarities between PT and PAT. The cross spectral coherence between motion and extensor e.m.g.s of the same side averaged 0.17 during PT and 0.68 during PAT. The cross spectral coherence between extensor e.m.g.s of the left and right forearms was 0.12 during PT and 0.69 during PAT. There was no significant difference, between the dominant and the non-dominant hand, in either the frequency or the amplitude of tremor during PT or PAT. PAT had a significantly higher amplitude of tremor than PT. The frequencies of PT and PAT did not differ significantly.

The results suggest that PAT is not simply an exaggerated PT. During PAT there was coherence between motion and e.m.g.s, neurologic tremor, coherence was not present during PT. During PAT there was evidence of an intersegmental or CNS link between extensor e.m.g.s of the two forearms. This link was not evident during PT. '

A COMPARATIVE STUDY OF BILATERAL HAND TREMOR: DURING POSTURE AND VOLUNTARY MOTION.

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Mr. Mark Summers produced the figures used in this study.

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ABSTRACT

A study was done to compare bilateral tremor of the hand during two different tremor provoking conditions, postural tremor (PT) and movement tremor (PAT). Specific tremor parameters quantified were, the coherence between wrist extensor e.m.g.s and the tremorous motion, the coherence between wrist extensor e.m.g.s of the two forearms, and the frequency and amplitude of tremor in the dominant and non-dominant hand.

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The results suggest that PAT is not simply an exaggerated PT. During PAT there was coherence between motion and e.m.g.s, neurologic tremor, coherence was not present during PT. During PAT there was evidence of an intersegmental or CNS link between extensor e.m.g.s of the two forearms. This link was not evident during PT.

INTRODUCTION

Tremor may be defined as a series of involuntary, rhythmic, and purposeless oscillatory movements involving a part or parts of the body moved by skeletal muscles (Brumlick and Yap, 1970). E.A. Schafer (1886) was the earliest author to quantify the rhythmic nature of tremors seen in various parts of the body and to hypothesize about the origin of these tremors. Theories advanced by various authors about origin, modulation or purpose of tremor have been based, mainly, on changes in the frequency and amplitude parameters of a tremor in relation to experimental variables. Researchers have quantified the frequency and amplitude components of tremor (Stiles, 1975, 1967; Elbe and Randall, 1976; Halliday and Redfern, 1956). Other researchers have recorded changes in tremor in response to mechanical and physiological pertubations (Stiles, 1967; Lippold, 1957,1970; Shiffman et. al., 1983). Researchers have also recorded the electrical activity associated with tremor (Mori, 1973, 1975; Hagbarth and Young, 1979; Marsden et al., 1969a).

Despite extensive study, knowledge of the origin or function of tremor has not advanced greatly beyond the level of early researchers. Holmes (1904) observed that "no single system in neurology exists whose anatomical or physiological basis is less understood than those of involuntary movements which, though varying in character and accompanying conditions, are collectively known as tremor." This statement is still remarkably valid today.

Three main theories are commonly used to explain the phenomenon of tremor. The first theory, a neurologic theory, states that synchronized e.m.g. activity is responsible for the background tremor found in all people. The proposed synchronization mechanism has been questioned. Stretch reflex modulation (Lippold, 1970), or Renshaw inhibition-rebound (Elble and Randall, 1976), are two synchronizing mechanisms which have been proposed. The second theory, a mechanical theory, states that the existence of a regular oscillation is the result of mechanical factors. The mass of the limb acts in conjunction with a system of variable tension springs, the musculature of the limbs, resulting in an unstable system which is subject to movement. The system is underdampened so motion results which is detected and modulated by neural factors (Stiles, 1967). According to this theory, the most important factor regulating the frequency and amplitude of tremor is the mass of the oscillating limb. The third theory, a combination neural-mechanical theory, states that tremor may behave as though it is either mechanically or neurally derived depending on the individual and the physiological state of the individual (Stiles, 1980; Howard, 1985). Marsden (1984) writes that physiological tremor represents the sum of a large number of different interacting mechanisms, all of which contribute to the tremor. Oscillation of a mechanical system, such as a human limb, is a function of both inherent mechanical properties of the system and of input into the system. The final output, tremor in this case, is influenced by both and can be changed in amplitude or frequency by alteration of either the mechanical properties or the input.

Definitions

The frequency of a tremor is the number of times the limb oscillates up and down in one second and is expressed in hertz (Hz).

Postural tremor (PT) is "tremor provoked by the maintenance of posture" (Findley and Capildeo, 1984). In this study, PT was recorded while the horizontally aligned pronated hands, supported at the wrist, were isometrically extended against the force of gravity. The recording of PT was kept short. The hands were extended for less than two minutes between rest periods in order to minimize muscular fatique. Keeping the muscles from becoming fatiqued helped to minimize the extrafusal muscle changes observed by Young and Hagbarth (1980).

Physiologic action tremor (PAT) is the same as "movement tremor" (Findley and Capildeo, 1984). The tremor analyzed is a "transition tremor", (Findley and Capildeo, 1984) recorded as involuntary oscillations of the wrist which occur as the wrist joint is voluntarily flexed after being in a position of 60 degrees extension. PAT is a position dependent tremor which Howard (1985) differentiated from PT based upon an unchanging frequency of the PAT in response to the addition of mass to the hand. PAT was recorded as the subject flexed and extended his unweighted hands.

The most appropriate and most accurate parameter to quantify tremor is acceleration (Brumlick and Yap, 1970). The best method of measuring and recording acceleration is with accelerometers (Gresty and Findley, 1984). There are several reasons why acceleration should be the parameter used to transduce tremor. Accelerometers are more sensitive to higher-frequency vibrations than are velocity or displacement devices. The acceleration of a limb most directly reflects the underlying muscular contraction. (Gresty and Findley, 1984).

For this study, tremor was first quantified in terms of accelerations. Acceleration values were converted to displacement values (displacement= acceleration divided by the square of the angular velocity, angular velocity= 2 x pi x frequency) in order to make the figures more meaningful to the average reader.

Gresty and Findley (1984) supported the use of spectral analysis and cross-spectral coherence to analyze frequency and coherency of tremor. Spectral analysis of the frequency of tremor is possible because tremor of the hand is a periodic function. Fourier's theory states that a periodic function can be represented as a series of sinusoidal components, each of which has amplitude and is fixed in phase with respect to the others. A waveform that is a pure sine wave has only one component, the fundamental. Waveforms that are more complex have a fundamental wave plus component waves at harmonic frequencies, whole number multiples of the fundamental frequency. The amplitude of the components indicates the shape of the waveform. The frequency of tremor which produces a peak in the power spectrum which is significantly greater than the other frequencies can be considered the main frequency of the oscillation. This is the frequency which exhibits the greatest degree of periodicity. (Bendat and Piersol, 1966; Pozos, Iaizzo, and Petry 1982).

Spectral analysis of signals has an associate function termed coherence. Coherence indicates the degree of relationship between two signals scaled from 0, indicating no relationship, to 1, indicating a completely deterministic relationship between signals. Coherence is a function in the frequency domain, and a level of coherence is calculated for each frequency present in the two signals being compared. The coherence function involves averaging cross-spectra with respect to individual autospectra and is associated with levels of statistical significance which become more reliable with increased numbers of averages (Gresty and Findley, 1984). One important application of the coherence function is in determining whether tremor occurring in separate parts of the body have a common generator (Marsden et al., 1969a). If signals in separate limbs have significant coherence, the conclusion may be drawn that a common rhythm generator must have access to discharge in both body parts at the same time (Gresty and Findley, 1984). Another application of coherence is to determine the relationship between e.m.g.s or neuronal action potentials and movement (Elble and Randall, 1976). Coherence was used in this study for both of these purposes.

OBJECTIVES

The first objective was to determine if a significant degree of coherence between acceleration and extensor e.m.g.s of the same hand occurred during either PT or PAT. The existence of e.m.g.s synchronized with motion is critical to distinguish neurally derived tremor from mechanically derived tremor (Elble and Randall, 1976). Several authors have proposed that the mechanism of tremor is different depending on the physiologic state of the muscle or the task used to elicit the tremor (Young and Hagbarth, 1980; Howard, 1985; Stiles, 1980). A difference in the degree of e.m.g.-acceleration coherence would suggest that the tremors associated with the two different conditions do not have the same origin or modulating mechanisms. The first null hypothesis was that when PT was compared with PAT no difference in the degree of coherence between extensor e.m.g.s and acceleration of the hand would be found.

The second objective was to quantify the cross spectral coherence of extensor e.m.g.s associated with tremorous hand motion during PT and PAT. A significant level of cross spectral coherence between the extensors of the two hands would suggest the existence of a connection, either segmentally or within the central nervous system, which links muscular activity of the hands. The second null hypothesis was that when PT was compared with PAT there would be no difference in the degree of cross spectral coherence between wrist extensor e.m.g.s.

REVIEW OF LITERATURE

The literature on physiologic tremor is confusing because many authors have tended to search for a single cause of the frequency or amplitude of tremor. In fact, a large number of factors probably interact to cause the phenomenon of tremor, including ballistocardiogram forces, muscle properties, motoneuron firing, receptor feedback, supraspinal influences and pharmacological influences (Marsden, 1984). All of these factors contribute to the regular tremor rate of 8-12 Hz observed by many authors (Stiles, 1976; Elble and Randall, 1976; Marshall and Walsh, 1956). The output of a mechanical system, a human limb in this case, is a result of both inherent mechanical qualities and inputs to the system. Final output of such a system can be changed in terms of frequency or amplitude in response to changes in either mechanical or input factors (Marsden, 1984).

The following review of literature highlights some of the theories used to explain the genesis and modulation of tremor. Many papers dealing with tremor have been published since Shafers' work in 1886. This review is by no means exhaustive; it is intended to familiarize the reader with main theories concerning the origin and purpose of tremor.

Motor Neuron Firing

Mori (1973) studied the electrical activity of soleus muscle motor-units during quiet standing. He found a narrow distribution of firing rate and a significant correlation coefficient between the means and standard deviation of the intervals obtained from the motor-units across subjects. Based on his results, Mori theorized the existence of a firing, rate-controlling, mechanism common to all subjects. Mori (1975) performed a more extensive analysis of the electrical activity of individual motor-units of the soleus muscle during quiet standing. Based on the results of this analysis, he stated that the interaction of motor-unit discharges is responsible for synchronization of motor-unit discharges. He postulated the existence of a disinhibitory neuronal network which could act to synchronize the independently firing motoneurons and lead to the oscillation of the stretch reflex loop. This closed loop system was considered as a site for a stored motor program.

Elble and Randall (1976) attempted to carefully establish the 8-12 Hz bursts of electrical activity from motor-units of the extensor digitorum comunis as being correlated with the tremor of the third digit. In four out of six subjects, a pronounced 8-12 Hz amplitude modulation in surface e.m.g.s was present and coherency analysis showed this modulation to be strongly correlated with an 8-12 Hz tremor. They also performed spectral analysis on 43 motor-unit spike trains active during extension of the wrist. Twenty-two of these spike trains had firing frequencies in the range of 10-22 spikes/sec. These spike trains produced statistically significant spectral peaks at 8-12 Hz in addition to the expected peak at the mean firing frequency. Coherency analysis demonstrated that the 8-12 Hz activities of these motor units was correlated with the 8-12 Hz finger tremor and surface e.m.g. modulation. The authors stated that the double discharge pattern found in these motor-units was indistinguishable from that believed to occur in motor-units as a result of Renshaw inhibition-excitation. Tremor was therefore postulated to have its frequency determined by Renshaw inhibition-rebound.

Muscle Properties

Marshall and Walsh (1956) found that the frequency of tremor did not vary either with the rate of movement or the level of force exerted. They stated that this finding contradicted one of the principles of motor unit behavior: The discharge frequency of individual motor-units increases with increased effort. Based upon this principle of muscle discharge frequency and the apparent paradoxical finding of their research, Marshall and Walsh proposed that physiological tremor occurred because only a finite number of motor nerve fibers exist. A rate of discharge below about 15/second in the motor fibers is converted to mechanical ripples by the muscles. Higher rates of neuronal discharge are blocked or filtered by the physical constitution of the muscle fibers. Marshall and Walsh stated that a regular tremor would not be seen if, when first recruited, the motor-units began firing at higher frequencies. However, the result of such initial high frequency firing rates would be jerky movement because the full force of tetanic tension would be realized abruptly. On the other hand, the tremor would be accentuated if the firing rate of the motor-units was lower. To obtain smooth control of movement the behavior of motor neurons must be closely matched to the properties of the muscles which they control. Marshall and Walsh did not speculate about whether special mechanisms exist to secure this control.

Properties of motor-unit contraction frequencies and recruitment order contribute to physiologic tremor (Marsden, 1984). Most motor neurons begin firing at a frequency of around 8 Hz, a frequency below the frequency of tetanic fusion. In human muscle fibers unfused motor-unit activity will tend to create oscillatory movement. Marsden stated that the recruitment of motor-units is in relation to the size of the motor-units, the Henneman principle. As the force of a contraction increases, smaller units increase their firing rates contributing less to the overall tremor. Larger motor-units are recruited with increasing force demands. These larger units begin firing at the 8 Hz rate causing a constant 8 Hz ripple to be superimposed on top of the fused contractions of smaller units. As the force of the contraction increases the size of the motor-units recruited increases so that the amplitude of the tremor increases with force exerted until maximal effort is approached (Marsden, 1984).

Lippold (1981) studied the amplitude characteristics of tremor after inducing fatigue in the muscle. The amplitude of the finger tremor was increased for up to four hours after a fatiguing task such as lifting a 1kg weight with a finger and holding the finger outstretched for two minutes, or isometrically maintaining an unweighted finger against gravity for one hour. In another experiment, the nerve supply to the finger muscle was blocked using an arterial pressure cuff. The subject was asked to exert a maximal effort with the finger for two minutes. If visual feedback was absent, the subject perceived muscular effort and movement even though no movement occured. After the resumption of nerve supply to the finger the amplitude of tremor was increased even when the subjects effort had been only a perceived effort. In another experiment the motor nerve responsible for motion of the third finger was stimulated. Stimulation at a level and duration necessary to accomplish a fatiguing task had no effect on subsequent tremor measurements. In all cases when the amplitude of the experimental finger tremor was increased the amplitude of tremor was not changed on the contralateral side. Neither a centralized factor or circulating hormones, such as adrenaline, would cause such an increase in tremor because the effect was not bilateral. Lippold did not think that the change in tremor was due to affecting the stretch reflex loop. He stated that the origin of the effect appeared to be in the CNS. The long term increase in tremor following a brief strong contraction seemed due, at least partially, to persistence of an increased degree of synchronized motor-unit firing which occurred during actual muscle contraction. No information on the locus or the mechanism of this change in synchronization was given. This synchronization worked in addition to the stretch reflex loop which Lippold stated was responsible for the base level of the tremor.

Hagbarth and Young (1979) reported important changes in extrafusal muscle characteristics in response to exertion of short duration and low intensity. During electrically induced supramaximal twitches of fatigued extrafusal muscle fibers the time from onset to peak tension was reduced by 10%, the half-relaxation time shortened by almost 15% and the peak force increased by 40% in comparison with fibers which were not first fatigued. These changes in extrafusal muscle characteristics would influence the response of a muscle to experimental variables (addition of weights, fatigue, motion, etc.) as much as any tremor mechanism.

Stretch Reflex Influences

Lippold (1970) observed tremor in the outstretched finger. When he applied a stepwise displacement to the finger the induced oscillation had the same frequency as the subject's PT. He placed an inflated pressure cuff on the arm to produce short periods of ischemia. This was thought to open the servo reflex loop by decreasing or eliminating afferent information from the oscillating limb. Ischemia caused a depression of all frequencies of the finger tremor and in some subjects caused the elimination of the tremor after three to four minutes. Ischemia had a similar depressing effect on the mechanically induced finger oscillations. Lippold concluded that the oscillation caused by mechanicaly tapping the finger and oscillation during PT were caused by the same mechanism; an instability of the stretch reflex servo loop.

Hagbarth and Young (1979) recorded neurograms from muscle spindle discharges (primarily from 1A's) and e.m.g.s associated with accelerometer records of the third digit. During small amplitude PT there was an obvious grouping of the spindle discharges, high during the stretching phase and low during the contraction phase, which indicated that muscle spindle sensitivity was sufficient to sense wrist motion of less than 0.1 . The intensity of the spindle discharge was not proportional to the amplitude of a given tremor cycle. The e.m.g.s did not exhibit obvious grouping during low amplitude PT. Fatiguing the muscles enhanced the tremor amplitude. Grouping of wrist flexor e.m.g.s and spindle neurograms correlating with movement was observed during tremor of fatigued muscles. The neural activity usually reached peak during the first half of the stretch phase. E.m.g. activity reached peak approximately 20 micro-seconds after the neural bursts and ended at the beginning of the shortening phase. The tremor was thus ballistic in the sense that muscle activity was electrically silent during the major part of the shortening phase. These results suggest that bursts of spindle activity alternating with pauses in spindle afferent input, may, by monosynaptic action, produce synchronization of discharge from an active motoneuron pool.

Young and Hagbarth (1980) studied the effect which stretch reflex enhancement had on PT. PT was studied for amplitude, e.m.g.s from muscles associated with tremulous limb movement, and neural activity from muscle spindle units. Measurements were taken after or during vibration, exercise, beta-adrenergic stimulation, the Jendrassik maneuver, and slow voluntary flexion-extension movements, all of which influence the stretch reflex in a positive manner. They reported that stretch reflex enhancement seemed to accentuate an already present involuntary tremor, whereas the stretch reflex was not obviously involved in the generation of the initial low level PT (Hagbarth and Young, 1979).

The e.m.g. activity became more synchronized with motion as the experiments progressed. The increased synchrony correlated with an increase in the amplitude of the tremor and increasing involvement of the stretch reflex.

Young and Hagbarth (1980) studied e.m.g. synchronization with motion during slow voluntary flexion-extension of the wrist. They observed small involuntary jerks in the direction of movement said to be due to the inability of the motoneuron pool to avoid mistakes in recruitment or derecruitment during movement. E.m.g. bursts associated with the jerks were accompanied by afferent spindle discharge as though the sudden involuntary movements involved not only skeletomotor but also fusimotor neurons. The fusimotor system is most sensitive during stretching, thus, oscillations would tend to be largest during eccentric contractions if modulated by spindle afferent signals.

Marshall and Walsh (1956) also noted an increased amplitude of tremor during movement. The amplitude change was greatest as the hand began flexion after being extended. This suggested stretch reflex modulation because the spindle is most sensitive when stretching an actively contracting muscle.

Stretch reflex as the determinant of tremor is objected to by several authors. Elble and Randall (1976) objected on the grounds that the mean frequency of tremor in several muscle groups does not vary even though there is a difference in the conduction delays associated with different muscles. Marsden et al. (1967) objected to the stretch reflex theory on the basis of his work with deaffernated patients. He found that the frequency of tremor remained the same in the deaffernated limb as the innervated limb although at a lessened amplitude. Stiles (1967) found that the frequency of tremor decreased with the addition of weights. If tremor were stretch reflex modulated, the frequency of tremor would not change in response to additional mass.

Mechanical Origin Of Tremor

Stiles (1967) studied the frequency and amplitude characteristics of physiologic tremor of the wrist. He added mass to the hands to determine if this would change any tremor characteristics. The addition of mass caused the hand to oscillate with increased amplitude at a lowered frequency. Stiles concluded that the relationship between mass and tremor was consistent with that of a second order underdampened mechanical system. A mechanical model was formulated on the basis of a cylinder with mass and dimensions similar to a finger, and spring constants with angles of attachments similar to the musculature of the forearm. When the relationship between added mass and transformed frequency was extrapolated, the predicted mass of the finger correlated well with the mass estimated by volume displacement.

Other authors have added weights to the limbs being studied and have reported no significant changes in frequency (Marshall and Walsh, 1956; Halliday and Redfern, 1956). The methods used by Stiles in his study differed from those used by others. He controlled for the elasticity of the system, muscular tension, by having the subjects maintain a constant e.m.g. level, a measurement which correlates with muscular tension.

Central Origin Of Tremor

Marsden, Meadows, Lange and Watson (1969a) examined PT in both hands simultaneously. The tremor did not differ significantly between the two hands in terms of frequency or amplitude. Cross spectral analysis found little moment to moment link between the movements of the two hands. Because a movement relationship between the hands did not exist, the authors stated that it was unlikely that the tremor was due to a central influence such as a central pacemaker within the nervous system or to ballisto-cardiac thrust which Marsden et al. felt had been suggested by Van Buskirk and Fink (1962).

Cardiac thrust is a central mechanical factor which has been shown to cause a measurable oscillation in all parts of the body (Brumlick and Yap, 1970). Tremor of cardiac origin has been referred to in the literature as physiological tremor, rest tremor, normal tremor, minor tremor, micro tremor, and ballisto-cardiac thrust. Brumlick and Yap specifically stated that this tremor was measured while the limb was at complete rest with no voluntary muscle contraction present. This is not the same condition which is present when muscles actively support a limb as during PT. Many authors have mistakenly confused the tremor at rest, which Brumlick and Yap called normal resting tremor, caused by cardiac thrust, with the tremor present during active muscle contraction, which Brumlick and Yap called normal PT. Marsden (1984) stated that the ballisto-cardiac impulse is responsible for approximatly 10% of the amplitude of PT.

Mechanical - Neural Basis Of Tremor

Stiles (1976) studied the effect that fatigue had on the frequency and amplitude characteristics of a tremorous outstretched middle finger. The subjects maintained extension of the finger against gravity for 15-45 minutes. During this time the amplitude of the tremor increased by a factor of 1,000 in some cases while the frequency of the tremor decreased by one-half. Based upon the results of this study Stiles theorized that asynchronously firing motor-units with a broad band frequency, acting on an underdampened mechanical system, are responsible for small amplitude tremors. The mechanism for large displacement tremors, tremor greater than 100 micra, was said to involve both mechanical and neural factors, a mechanical-reflex oscillator mechanism.

Stiles (1980) studied the coherence of demodulated extensor e.m.g. activity with frequency and amplitude of hand tremor during 10 to 60 minutes of continuous extension and with 100 g to 500 g of mass added to the hand. He found a high coherence between e.m.g.s and oscillation of the same hand especially during tremor of high frequency and amplitude. He also noted a linear relationship between the log of the e.m.g. amplitude and the log of the tremor amplitude. The appearance of correlated electrical activity of the muscles controlling the limb suggested to Stiles either a reflex or central oscillator mechanism for the oscillations.

Howard (1985) studied PT of the finger and the response of the PT to the addition of weights. He also quantified a tremor which he called PAT observed during the voluntary movement of the subject's hand as the hand began flexion from an extend position. Based on the change in the subjects PT characteristics after the addition of weights, Howard identified two separate groups of subjects. One group had a low frequency, high amplitude PT which responded to the addition of weight to the hand in a manner which would fit with Stiles' (1967) mechanical theory; the tremor increased in amplitude and decreased in frequency. The second group had a PT which responded to the addition of weights as if the tremor were of neural origin; the tremor decreased in amplitude and maintained a constant frequency. Based on the results of his study, Howard agreed with Stiles (1980) that low amplitude PT has components which fit into both a neural and a mechanical model of origin. All subjects had a PAT which responded as though it were neurally controlled; the addition of weight did not influence the frequency of the tremor. Because of this, Howard concluded that PAT was not simply an exaggerated PT since it did not show any of the characteristics of a mechanically influenced system.

Hagbarth and Young (1979) stated that the small amplitude tremor observed during postural fixation before fatigue acted as if it were mechanically controlled; no synchronization of e.m.g. activity was observed. The large amplitude tremor observed after enhancement of the stretch reflex appeared to be neurally driven; there were distinct groupings of e.m.g.s and spindle neurograms and synchronization of e.m.g. activity with tremor oscillation occurred.

Function Of Tremor

Marsden et al. (1969b) studied tremor of the finger with particular reference to changes with age. They found that although the peak frequency did not vary between adults and children, only 60% of the children, under 16 years old, had a dominant tremor frequency. A dominant tremor frequency was found in 95% of the adults tested. The authors noted that children tend to be clumsy in their fine motor control and theorized that the more random nature of their motor activity, the lack of a consistent dominant tremor, may be responsible for this lack of fine motor control.

Marshall and Walsh (1956) noted a slower frequency in the tremor of young children. A lower frequency of tremor should result in a tremor of increased amplitude. Children may thus tend to be more clumsy due to an enhanced amplitude, lower frequency tremor.

Gresty and Findley (1984) note two prime considerations relating to bodily movements such as tremor. The first consideration is the necessity to prevent structures from going into oscillations and to contain and dampen out oscillations when necessary. The second consideration relates to the structure of the body. The body is a jointed framework supporting inertial loads with viscoelastic properties, controlled by a muscular system working at a mechanical disadvantage. Working at a mechanical disadvantage can be offset somewhat if a system is operating close to the natural resonance of the system. The body needs to work with natural resonance tendencies in order to conserve energy in spite of the fact that the resonance causes instability. According to the authors, tremor arises in structures normally responsible for coordinating movement and is the risk that the nervous system takes to conserve energy. Tremor occurs with a similar frequency at different sites in the body because of the necessity to coordinate movement in several body parts at once.

METHODS

Subjects

The subject pool consisted of two women and eleven men. They ranged in age from sixteen to thirty five. None had a history of neurological or physical abnormalities. The dominant hand was determined to be the hand used for writing. All were asked if they practiced any activitities such as piano playing which required a high degree of simultaneous two hand activity, since it was felt that such activities might influence interhand coherence.. All subjects answered negatively. The subjects were asked to refrain from caffine and nicotine for four hours prior to the experiment. Exercise prior to the experiment was not controlled for.

Recording

The experiment required six channels of data, an acceleration and two electromyographic signals from each arm. Electromyograph signals (e.m.g.s) were recorded from bipolar electrodes placed longitudinally, two cm apart, over the body of the extensor digitorum, and the body of the flexor digitorum superficialis. Palpation was used to isolate that portion of each muscle most responsible for movement of the third digit. Proper placement was confirmed by visual inspection of oscilliscope tracings of e.m.g.s during flexion-extension of the wrist prior to the experiment. The e.m.g. signals were amplified by Grass P511 A.C. preamplifiers (bandwidth 100-1000 Hz) and recorded on a Hewlett/Packard 3968 tape recorder (bandwidth 0-2500

Hz) for future analysis. To transduce the frequency and amplitude of the tremulous motion, a calibrated accelerometer (Kulite model GY-125-10, sensitivity 9.4 mV/G, natural frequency 670 Hz, weight 0.5g) was taped just proximal to the distal interphalangeal joint of the third digit. The signal from the accelerometer was amplified appropriately and recorded on the tape recorder. The fingers were adducted and taped together and the thumb was taped in an adducted position against first digit so the hand acted as a unit.

Experimental Conditions

The experiments were conducted between 9:00 A.M. and 2:00 P.M. to control for the diurnal variation of tremor (Tyrer and Bond, 1974). All studies were conducted in a quiet room with the subject seated in a comfortable chair. Subjects were instructed to adduct the arm at the shoulder and flex the elbow so that the pronated forearm lay comfortably on a rigid flat surface supported down to the head of the radial styloid process. This position allowed for unhindered flexion and extension of the wrists.

All subjects were wired to collect the same data during both PT and PAT. When testing PT the unweighted hands were extended to a horizontal position, zero degrees of wrist flexion-extension, and held isometrically against gravity for two minutes. Subjects were told to hold the hands steady using minimal muscular effort. Acceleration and e.m.g.s were recorded simultaneously from each forearm and hand as the subject maintained the horizontal position.

After the PT task, the subject rested for two minutes. The subject then practiced the flexion-extension movement used to elicit the PAT, described by Howard (1985). Familiarization with the range and the frequency of motion requested was necessary. The task required flexion-extension through a range of motion 60 degrees extension - 60 degrees flexion in time with the visually displayed 0.25 Hz sine wave. The range of motion was selected because it was comfortable for all subjects and in all cases required the subject to use the flexor muscle group to complete the flexion range. A sine frequency of four seconds for each complete flexion-extension cycle was used to closely duplicate Howard's work. The subjects were instructed to stay in time with the sine wave and to match the timing of the wave by being in a position of full flexion when the sine wave was most negative and a position of full extension when the sine wave was most positive with minimal pausing at either extreme of motion. After the practice session the subject rested for two minutes before beginning the recorded task. During the PAT task, acceleration and e.m.g.s were recorded while the subject flexed and extended the hands for two minutes.

Care was taken to keep recording sessions short in order to minimize fatigue, since fatigue and exercise have been shown to alter the characteristics of tremor (Lippold, 1981; Young and Hagbarth, 1980). The subjects in this study reported no feeling of fatigue and strip chart recordings of the frequency and amplitude of PT and PAT showed no changes over the recording period. For these reasons, it appeared that fatigue played no significant role in this study.

Data Selection

Selection of appropriate sections of PT to analyze was fairly simple. Strip chart recordings of the data were previewed to determine if there were any unusual portions, large spikes in acceleration or e.m.g. activity not indicative of normal tremor, which would be inappropriate for analysis. Unusual sections and sections prior to stabilization of the

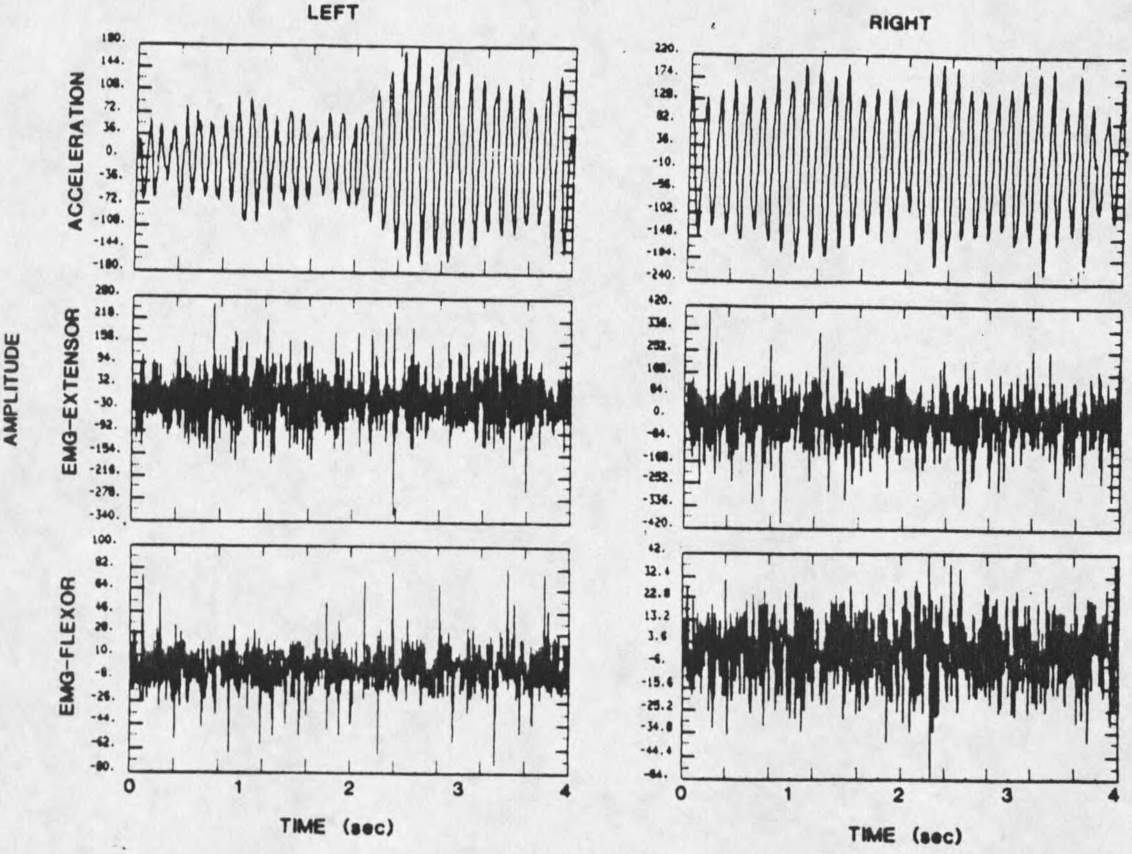

Figure 1: Digitized record of the electrical activity during PT. The scale of the Y axis (amplitude) is 2.5 mV/increment. The amplitude of acceleration, especially of the left hand, varies considerably with time. This variation has been reported to be due to a variation in balistocardiogram force (Marsden 1984).
No visually apparent, consistent relationship between the e.m.g.s peaks and the acceleration peaks is noted. There does not seem to be a consistent relationship between the e.m.g.s of the flexor and extensor groups.
The left hand has a tremor frequency on the acceleration channel of 8 hz. The right hand has a tremor frequency on the acceleration channel of 8.75 hz.

tremor were avoided. Figure 1 is a graph of the data before the computer analysis has been done. Three separate sections of data were analyzed by computer (a D.E.C. Micro PDP-II) for amplitude, frequency, and coherency analysis. The mean of these three segments represented the frequency, amplitude, and coherence characteristics of the subjects PT.

Selection of segments of PAT appropriate for analysis was more complex due to variances of inter-hand position. Howard (1985) defined PAT of the hand as the high amplitude and frequency tremor seen most clearly as the hand begins a controlled flexion movement from an extended position. Strip-chart recordings viewed in this study made it very clear that PAT is extremely position dependent. Data was therefore previewed from strip-chart recordings to determine when PAT was well defined and also when the position of the two hands was equal. Data analyzed by the computer represented, as closely as possible, tremor with the two hands at equal positions in the range of motion. Figure 2 represents the data before a head to tail concatenation of the desired section by the computer. Three segments were computer analyzed. The mean of the three represented the frequency, amplitude, and coherence characteristics of the subjects PAT.

Analysis

Analysis of the recorded acceleration and e.m.g.s from each hand for frequency and amplitude characteristics was done on a D.E.C. Micro PDP-11 computer. Appropriate sections of PT and PAT were sampled by the computer by replaying the taped records at one quarter of the recording speed. The analog signal was sampled and digitized at 64 samples per second which gave an effective sampling rate of 256 samples per second. The digitized record then had the mean subtracted to remove any D.C. offset.

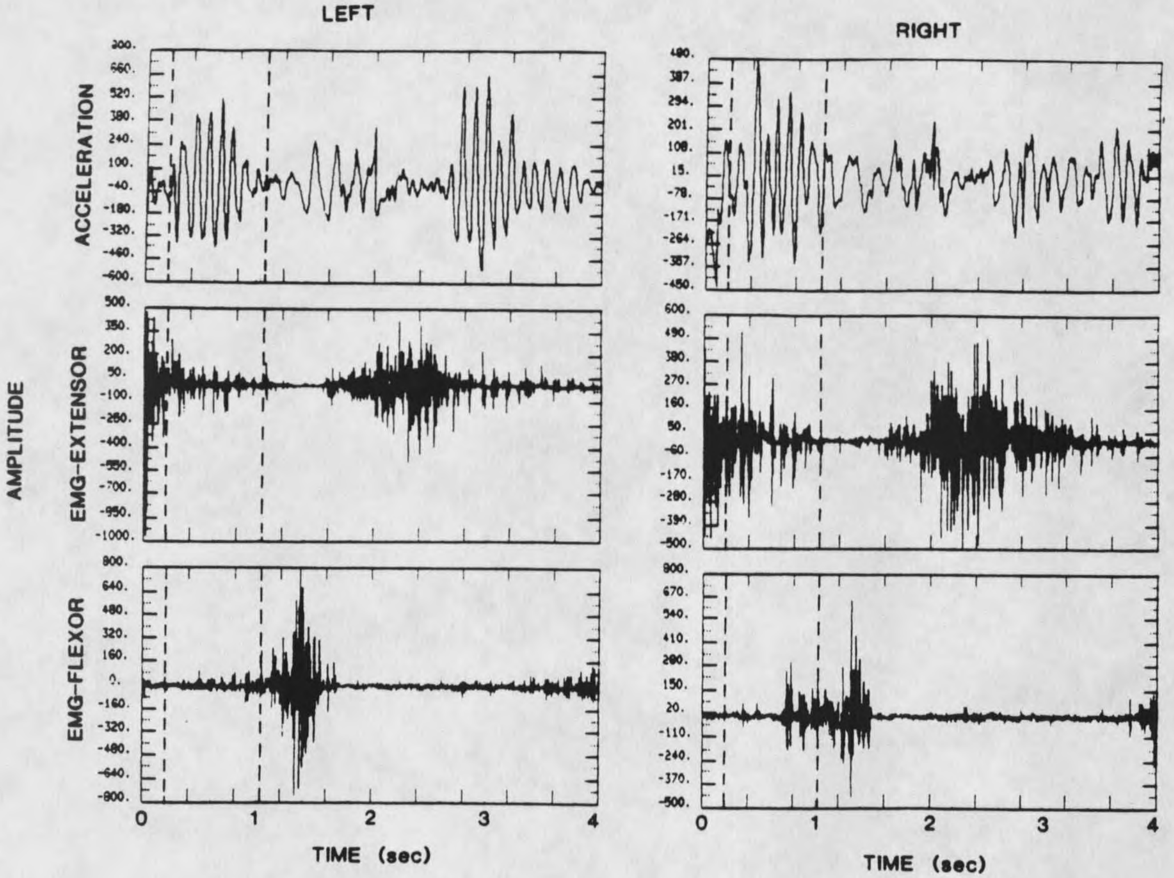

Figure II. Digitized record of the electrical activity during PAT. The scale of the Y axis (amplitude) is 2.5 mV/increment. The portion of the tremor which was specifically analyzed is between the dashed lines.

Note that during the analyzed portion the extensor e.m.g.s are more distinct and coincide closely with the acceleration peaks. Flexor activity is greatest during periods of low extensor activity. Also, when flexor activity is high, the frequency of the tremor appears to be less.

Because the analyzed portion of PAT involves very little flexor activity, the coherence between flexor e.m.g.s and acceleration was not considered.

PAT records were high pass filtered (5 Hz) to remove slow wave motion from the signal which might have been caused by the flexion-extension motion of the hand. PT records were not high pass filtered.

PT recordings of four seconds duration were sampled by the computer (see Figure 1). This was a sufficient time length to give 1024 data points, the number calculated to be sufficient for frequency analysis and resolution (Bendat and Piersol, 1966).

The time length of PAT is too brief, O.5-1.5 seconds, to yield 1024 continuous data points. To produce 1024 continuous data points the portion of the record which contained the defined period of high amplitude motion was exised from the remaining digitized record (see Figure 2). This portion of the record was then duplicated and concatenated in a head to tail fashion enough times to yield 1024 data points (see Figure 3).

The remainder of the analysis was identical for both PT and PAT. E.m.g. records were demodulated by high pass filtering (1 Hz), full wave rectification, and low pass filtering (30 Hz). These records were then substituted with cosine waveforms to smooth potential inconsistencies caused by joining. The smoothing was done by finding the mean of the first 112 relative maxima, calculating the peak to valley or valley to peak distances in the demodulated e.m.g. record and calculating the frequency for that portion of the waveform. An appropriately increasing or decreasing portion of a cosine waveform, with an amplitude equal to the mean of the maxima, was then substituted in place of the actual demodulated e.m.g. segment. The smoothing process occurred on all channels of data, keyed to a criterion channel which in all cases was the channel from the acceleration of the subject's dominant hand.

The computer next subjected the records to auto correlation and power spectral density analysis, in accord with equations found in Bendat and Piersol (1966). Results of the computer analysis yielded power spectral plots of variance relative to frequency.

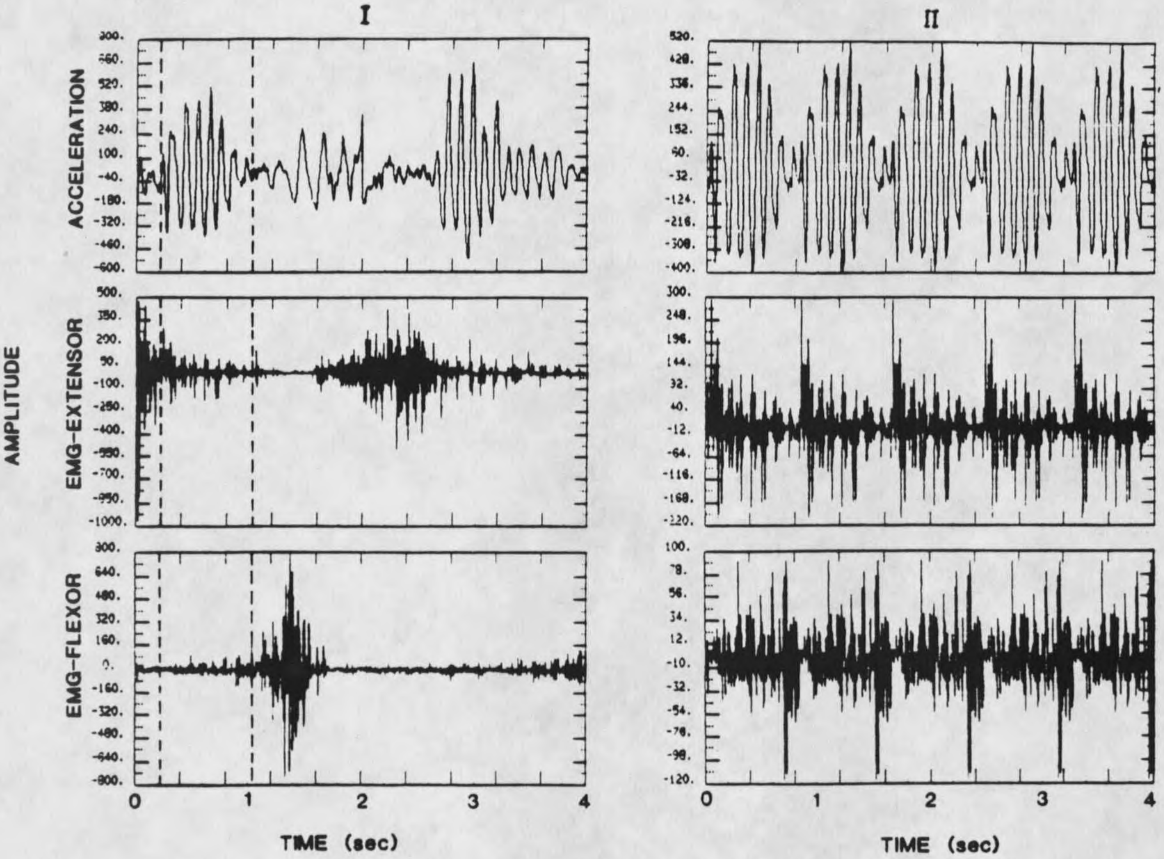

Figure III. Column I is movement tremor with the defined PAT section between the dashed lines. Column II is the defined PAT portion exised and concatenated enough times to yield 1024 data points.
The section to be analyzed was determined and marked on the acceleration channel of the subjects dominant hand. The same section was then marked on all other channels.
The amplitude of column II appears greater due to a change in the scale.

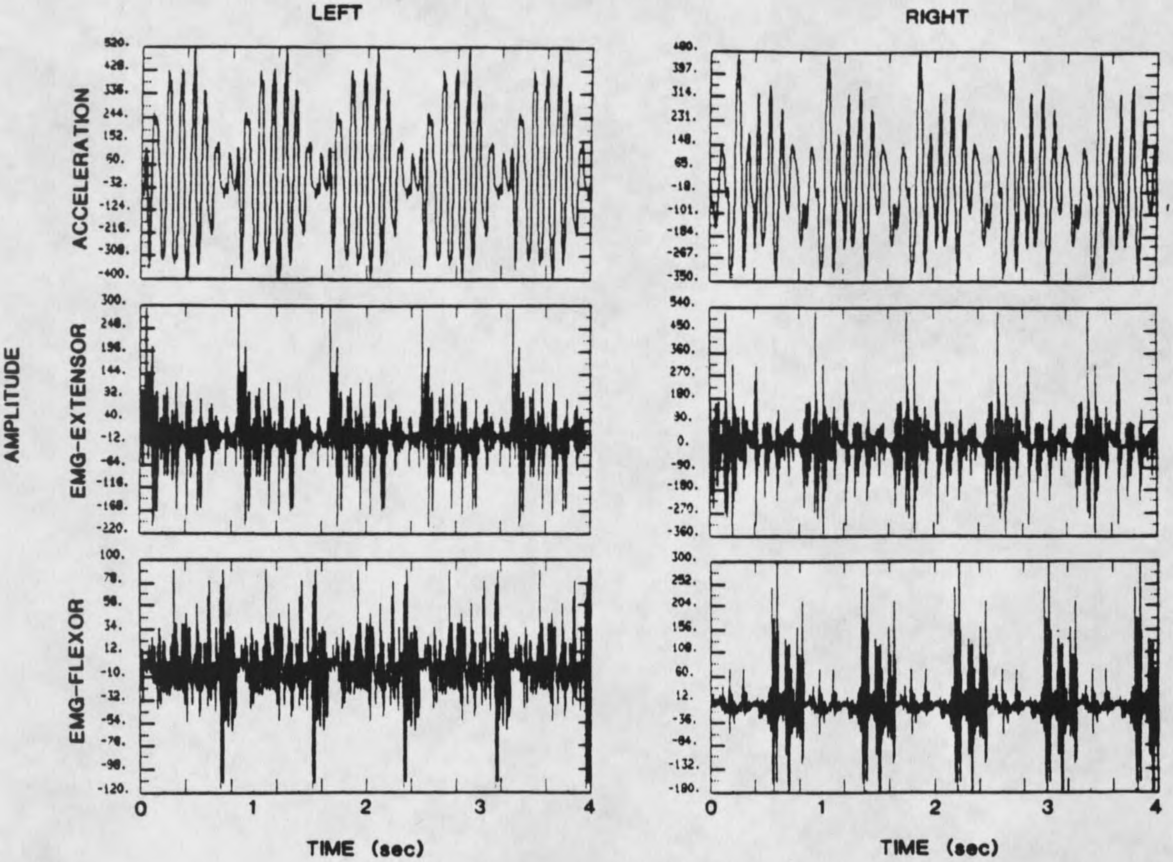

Figure IV. The excised portion of the PAT data from Figure II concatenated enough times to yield 1024 data points. In this section it is visually apparent that extensor peaks lead acceleration peaks consistently. Flexor peaks coincide with periods of low amplitude extensor and acceleration activity.

The subject is right hand dominant and stated that he participated in a large number of sporting activities some of which involved use of both hands (X-C skiing).

Calculations

Calculation of the frequency and amplitude values from tremor spectral plots is described by Stiles (1976). The power spectrum can be considered as a plot of the total variance of the signal. In this study, the spectrum usually consisted of a single spectral band with a peak frequency which was taken to be the frequency of that signal (See Figure 5). The root mean square (r.m.s.) amplitude of the signal at that frequency can be calculated from the spectral band based on the assumption that each spectral band had arisen from a single-frequency source. After the above spectral analysis, the spectral band of a single-frequency signal would contain three or four variance values, at three or four adjacent frequency values. The sum of the variance values would be equal to the total variance at the central frequency of the spectral band. The r.m.s. acceleration of the signal can then be calculated as the square root of the total variance at that frequency. The r.m.s. displacement can be calculated by dividing the r.m.s. acceleration by the square of the angular velocity.

The e.m.g. spectra had the peak frequency calculated the same way as the acceleration channel. The square root of the total variance would be equal to the r.m.s. voltage of the mean of the signals first 112 relative maxima.

The frequency and amplitude of tremor in the dominant hand was compared to the non-dominant hand for each subject during PT and PAT. Paired T's was the statistical method used. The level of significance chosen was 0.05.

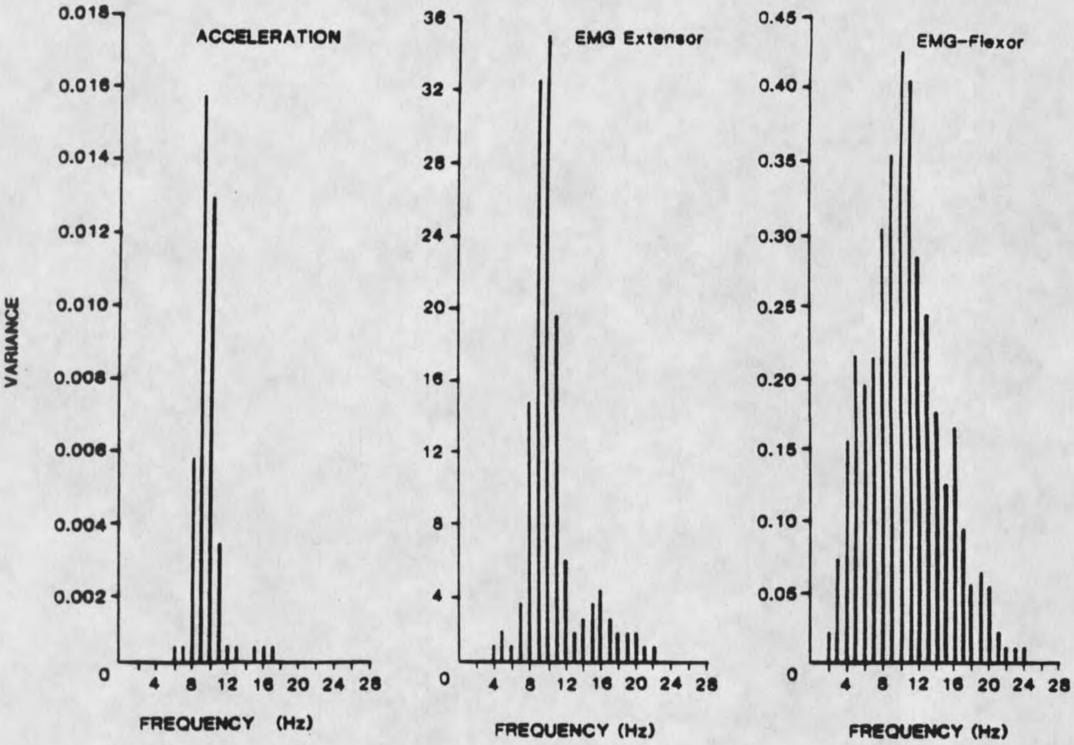

Figure V. Power density spectra of acceleration and two e.m.g.s recorded during PAT for 1 subject. The first plot is of the variance of acceleration (cm/s^2) vs the frequency of acceleration recorded. The second and third plots are of variance in mV vs frequency of e.m.g.s recorded from the extensor digitorum and the flexor carpi ulnaris respectively.

RESULTS

The first hypothesis stated that there would be no difference in the degree of coherence between the extensor e.m.g.s and acceleration of the same hand, PT compared to PAT. According to Stiles (1980), a coherency level of 0.40 or above indicates that one signal is significantly related to another signal. Table 1 lists the degree of coherence between the acceleration and extensor e.m.g.s of the same hand present during PT and PAT. None of the subjects showed any significant coherence between the extensor e.m.g.s and the motion of the same hand during PT. The average level of coherence during PT was 0.17, less than what could be expected to occur by chance alone (Marsden et al., 1969a). All of the subjects showed a significant level of coherence between the extensor e.m.g.s and acceleration of the same hand during PAT. The average level of coherence during PAT was 0.70, greater than what would be expected to occur by chance alone. The first null hypothesis is thus rejected. There was a difference in the degree of coherence between extensor e.m.g.s and acceleration of the same hand when PT was compared to PAT.

The second hypothesis stated that there would be no significant difference between the cross spectral coherence of extensor e.m.g.s during PT compared with extensor e.m.g. coherence during PAT. Table 2 lists the degree of coherence between the extensor e.m.g.s which occurred during PT and PAT. None of the subjects had a significant level of coherency between the extensor e.m.g.s during PT. During PAT all of the subjects except one had a significant level of coherency between the extensor e.m.g.s. The second null hypothesis is thus rejected. There was a difference in cross spectral coherency of extensor e.m.g.s associated with hand tremor when PT was compared to PAT.

Table 1. The degree of coherence between extensor e.m.g.s and hand tremor during PT and PAT. A coherence of greater than 0.40 indicates a significant relationship. The coherence is no better than chance during PT. It is clear that motion and e.m.g.s are significantly correlated during PAT. Note the difference of coherence between the dominant hand and the non-dominant hand during PAT.
Two of the subjects in the study did not complete both the PT and the PAT experiment so their data was not included in this table. A third subject did not exhibit a dominant tremor frequency and so was not included in the data for this table.

Subject	Coherence during PT		Coherence During PAT	
	Dom	Non-Dom	Dom	Non-Dom
1	0.40	0.00	0.84	0.46
2	0.38	0.26	0.50	0.42
3	0.18	0.32	0.78	0.78
4	0.18	0.32	0.92	0.30
5	0.12	0.30	0.74	0.62
6	0.02	0.16	0.76	0.72
7	0.00	0.00	0.92	0.86
8	0.04	0.12	0.86	0.38
9	0.20	0.14	0.88	0.76
10	0.26	0.02	0.92	0.42
Average	0.18	0.16	0.81	0.57

Table 2. A comparison of the extensor e.m.g. cross-spectral coherence, during PT and PAT. A coherence value above 0.40 indicates a significant relation between the signals. The high coherence during PAT supports the existence of a central or segmental connection between the musculature of the two hands. The connection is not present during PT. Data from four subjects was not included in this table either because they did not complete both tasks or because one of the e.m.g.s did not exhibit a stable frequency.

Subject	Coherence During PT	Coherence During PAT
1	0.00	0.66
2	0.16	0.38
3	0.12	0.14
4	0.12	0.72
5	0.10	0.48
6	0.18	0.46
7	0.26	0.98
8	0.00	0.68
9	0.10	0.72
Average	0.12	0.68

DISCUSSION

Significant Findings Related to PT

Cross spectral analysis was used to determine if coherency existed between e.m.g.s of wrist extensors and acceleration of the same hand during PT. No significant coherence was found (see Table 1). This agrees with the work of Young and Hagbarth (1980) who found no significant grouping of muscle e.m.g.s at the small amplitudes of physiologic tremor. The lack of a significant level of coherence between the extensor e.m.g.s and acceleration of the same hand agrees with the mechanical theory of small amplitude tremor proposed by Stiles (1980); small amplitude tremor results from mechanically induced motion, modulated and perpetuated by spindle sensitivity.

Cross correlation analysis was used to determine if coherency existed between the extensor e.m.g.s of the two hands during PT. Finding a high degree of coherency between the two e.m.g.s would support the existence of an intersegmental link or a common CNS connection. No significant cross spectral correlation between the extensor e.m.g.s of the two hands was found in any of the subjects during the PT segments sampled. There would seem to be no central force or segmental connection affecting the production or maintenance of PT.

Coherency between the acceleration of the two hands during postural tremor in this study and by Marsden et al. (1969a) was lower than could be expected to occur due to chance. Yaps and Boshes' (1967) suggestion that postural tremor represents oscillations due to ballisto-cardiac impulses is incompatible with the results of this study or with the study by Marsden. A ballisto-cardiac force should cause correlated acceleration of the hands as well as a tremor with nearly equal frequency and amplitude characteristics even though the distance from the heart to the hands is not equal. A CNS pacemaker is also incompatible with the data. A pacemaker system should produce a degree of coherence between acceleration of the two hands even though nervous input to muscles is heavily filtered by dynamics of the musculoskeletal system (Marshall and Walsh, 1956). Lack of a moment to moment link between tremor of the two hands indicates that many factors responsible for fluctuations in tremor act upon two distinct systems which, because they share the same environment, have similar properties (Marsden et al., 1969a).

The dominant hand was compared to the non-dominant hand in terms of the frequency and the amplitude of tremor which occured during PT (see Tables 3 & 4). Paired T tests showed no significant difference, in frequency or amplitude of tremor, between the two hands. Marsden, et al. (1969a) reported similar findings. This finding neither substantiates or refutes a theory that a consistent PT is a physiologic base for fine motor control (Marshall and Walsh, 1956; Marsden et al.,1969b). Consistent tremor may develop in both hands simultaneously as a maturational process. Other factors would be more important in the selection of a dominant hand especially considering the finding by Marsden et al. (1969b), that a "consistent" tremor does not always develop in children until the age of 15, long after the time when hand dominance is usually determined. Gresty and Findley (1984) stated that frequency and synchronization of tremor occurs at the level of neuronal membranes and exists due to the necessity of coordinating movements in several body parts. Coordination would only be possible if the tremor was of comparable frequency and amplitudes in both limbs. Based on this, the tremor of the two hands would

Table 3. Comparison of the r.m.s. displacements (in micra), and frequency (in Hz), between non-dominant hand (1), and dominant hand (2), recorded from the acceleration channel. There was no significant difference between the dominant and non-dominant hand in frequency or amplitude.

SUBJECT	PT-DISP(1)	PT-DISP(2)	PT-FREQ(1)	PT-FREQ(2)
1	69.4	23.1	8.0	8.0
2	27.9	71.6	7.0	8.3
3	23.8	41.3	8.0	7.7
4	37.6	31.0	7.7	7.7
5	34.4	58.8	8.0	8.0
6	29.5	21.2	8.0	10.0
7	17.2	20.3	9.3	9.3
8	27.0	29.5	9.3	8.3
9	7.9	33.6	7.3	7.0
10	31.7	48.1	8.0	8.0
11	40.3	19.0	8.0	9.0
12	57.6	52.2	8.0	8.7
13	30.6	46.1	7.7	7.0
Mean	33.45	38.14	8.02	8.23
	S.E.M.±4.4	S.E.M.±4.6	S.E.M.±0.18	S.E.M.±0.24

Table 4. Comparison of r.m.s. amplitudes (in microVolts), and frequency (in Hz), between the non-dominant hand (1) and the dominant hand (2), recorded from the extensor channels during PT. No significant difference was found between the hands in terms of amplitude or frequency during PT.

SUBJECT FREQ(2)	AMPLITUDE(1)		AMPLITUDE(2)	FREQ(1)
1	2.7	3.8	13.7	11.7
2	3.6	3.8	12.3	12.0
3	2.4	3.2	10.7	12.7
4	4.1	3.6	13.3	12.3
5	3.6	2.5	12.7	13.0
6	4.1	8.3	12.3	13.3
7	1.8	2.0	14.3	14.3
8	3.9	6.7	14.3	11.7
9	2.8	3.8	11.3	8.3
10	0.7	1.3	9.5	13.3
11	3.5	6.1	13.0	13.7
12	5.3	2.9	13.3	13.0
13	2.9	2.6	11.7	11.3
Mean	3.18	3.89	12.49	12.35
	S.E.M.±0.32	S.E.M.±0.55	S.E.M.±0.39	S.E.M.±0.42

be expected to be comparable in terms of frequency and amplitude. In this study, a tremor with similar frequency and amplitude characteristics was present in both hands of normal, mature people.

Significant Findings Related to PAT

Cross spectral analysis showed a significant level of coherency between the extensor e.m.g.s and acceleration of the same hand during PAT (see Table 1). Finding coherency between motion and e.m.g.s supports a neurologic basis for PAT. This agrees with other authors (Young and Hagbarth, 1980; Stiles, 1980; Howard, 1985) that higher amplitude tremors, brought on by fatigue or by motion, have a neurological origin. PAT should be differentiated from low amplitude PT which showed little if any neurologic pattern. These results are in agreement with Marsden's (1984) statement that tremor is dependent upon the state of the individual and the task demanded. The mechanical-neural theory of tremor seems to be most valid.

Differences between the two hands in the degree of e.m.g.-acceleration coherency are interesting. All subjects had a significantly high degree of coherence, greater than 0.40 (Stiles, 1980), within the dominant hand, average coherence = 0.81. Eight of the ten subjects had a significant level of coherance within the non-dominant hand, average coherence = 0.57. The difference in the coherence, e.m.g.s with acceleration, may be a factor which makes dominant hand fine motor control superior to non-dominant hand fine motor control. Through practice, repetition or perhaps hard wiring the neural circuits are more facilitated in the dominant hand than in the non-dominant hand (Pozos, personal communication) and neural signals become more closely correlated with voluntary motion.

Differences in coherence may also partially explain the result that the amplitude of tremor was greater in the dominant hand than the non-dominant hand for eight of thirteen subjects (Table 5). Greater coherency between e.m.g.s and acceleration should cause motion of greater amplitude. Alternate explanations for the amplitude difference are that the muscle spindle of the dominant side is either more sensitive or the afferent signal from the spindle is more facilitated and thus more apt to cause a contraction in response to stimulation. Also, there may be a difference in the strength of the motor-units stimulated by afferent stretch reflex input. Thus a given contraction would cause greater amplitude of acceleration. These explanations fit in with a neural theory for origin and modulation of tremor. An explanation based upon Stiles' (1967) mechanical theory would be that the dominant hand is heavier than the non-dominant hand. The hands weren't weighed in this experiment but a difference could be expected. The weight of the heavier hand would create a greater input to the stretch reflex loop and thus a greater muscle response.

Cross spectral analysis of the data showed that a significant level of coherency existed between the extensor e.m.g.s of the two hands during PAT (Table 2). This finding is further argument that the two tremors, PT and PAT, are neurologically different (Stiles, 1980; Howard, 1985). The high coherency level between the extensor e.m.g.s during PAT strongly suggests the existence of a connection, either segmentally or within the CNS which links muscular activity of the two hands. This study does not establish where the connection might be.

Statistical analysis by paired T-tests showed no significant difference in the frequency or amplitude of PAT tremor, dominant versus non-dominant hand (Table 5). Differences in fine motor control between hands are not associated with differences in the frequency or amplitude of PAT.

Table 5. Comparison of the r.m.s. displacements (in micra), and frequencies (in Hz), between non-dominant hand (1) and dominant hand (2), recorded from the acceleration channel during PAT. There was no significant difference between the dominant and non-dominant hand in terms of frequency or amplitude of tremor.

SUBJECT	PAT DISP(1)	PAT DISP(2)	PAT FREQ(1)	PAT FREQ(2)
1	261	88	10.0	9.0
2	290	507	10.0	9.8
3	251	476	8.3	6.3
4	312	342	8.3	7.0
5	548	212	5.3	8.6
6	430	104	6.7	11.0
7	265	664	8.0	8.7
8	156	411	8.7	7.3
9	393	239	9.8	6.5
10	277	167	10.5	11.3
11	310	418	11.3	8.3
12	285	411	10.3	8.7
13	294	530	7.8	7.3
MEAN	301 Microns	363 Microns	8.59 Hz	8.70 Hz
	S.E.M.±26	S.E.M.±48	S.E.M.±0.49	S.E.M.±0.42

Table 6. Comparison of e.m.g. amplitudes, (in microvolts), and frequency (in Hz), between the non-dominant (1) hand and the dominant hand (2), recorded from the extensor channel during PAT. There was no significant difference between the dominant and non-dominant hand in terms of frequency or amplitude of tremor.

SUBJECT	AMPLITUDE(1)	AMPLITUDE(2)	FREQ(1)	FREQ(2)
1	7.3	7.8	9.0	10.3
2	6.1	9.1	10.3	10.5
3	3.5	1.7	9.6	10.0
4	2.3	3.2	10.0	11.6
5	3.0	4.1	12.0	10.6
6	9.1	11.3	9.3	11.0
7	3.7	4.5	11.3	10.3
8	4.7	7.3	13.7	14.0
9	4.2	6.7	10.5	10.5
10	12.9	12.0	11.3	12.0
11	7.1	7.7	11.3	8.7
12	14.2	12.9	11.0	12.0
13	3.6	4.4	10.0	11.8
MEAN	6.48	6.94	10.72	11.02
	S.E.M.±1.0	S.E.M.±1.0	S.E.M.±0.35	S.E.M.±0.36

SUMMARY

The study was done to compare tremor of the hand present during two different conditions, maintained posture (PT) and purposeful movement (PAT). During the two conditions of tremor; the cross spectral coherence between the acceleration and extensor electromyograms (e.m.g.s) of the same hand and the cross spectral coherence between the extensor e.m.g.s of the two hands were determined.

Results

1. During PT no significant coherence was found between the extensor e.m.g.s and motion of the same hand.
2. During PAT all of the subjects had a high degree of coherence between the extensor e.m.g.s and motion of the same hand.
3. When compared during PAT, there was a difference between the dominant hand and the non-dominant hand on the degree of e.m.g.-motion coherence; 0.81 dominant hand, 0.57 non-dominant hand.
4. During PT none of the subjects had a significant level of cross spectral coherency between the extensor e.m.g.s of the two hands.
5. A significant level of cross spectral coherency between the extensor e.m.g.s occurred during PAT for all of the subjects.
6. The study argues for the existence of a central or segmental connection between the muscles most responsible for tremulous movement during PAT.

7. The central or inter-segmental connection was not present during the low amplitude PT observed during this study.

8. No significant difference was found to exist between the two hands in terms of the frequency and amplitude of tremor during PT or PAT.

10. The coherency between motion of the hands was less than chance during both PT and PAT.

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