Characteristics of Physiological Tremor in Five Fingers and Evaluations of Fatigue of Fingers in Typing

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Physiological tremor, which is the invisible mechanical vibration of body part, was measured for five fingers. It was obtained that the power spectrum always has two peaks at 10 and 25Hz for each of the five fingers. The peaks were considered to be generated in the following two loop systems: The component of the lower frequency originated from the central nervous system as a long loop, and that of the higher frequency originated from the muscle-spine loop system as a short loop. The total power, which was the sum of power spectra ranging from 1.5 to 50Hz, was defined as an evaluation index, and it showed characteristic results for the five fingers. The muscular load produced by two hours of typing work was responsible mainly for the increase of total power and for the change of peak frequencies. The mechanism for the change of the power spectrum due to muscular load was well explained by the two-loop theory. It was found that the fatigue of the fingers due to muscular load could be evaluated by the total power. (Ann. Physiol. Anthropol. 11(1): 61-68, 1992)

Key words: Physiological tremor, Finger's function, Typing work

Physiological tremor is the invisible mechanical vibration of body parts like hand and finger. The phenomenon was found in 1876 by Beaunis (Friedlander, 1956), and physiological tremor for man was measured in the first place by Schäfer in 1886. This discovery is older than that of other mechanical rhythms (Usui et al., 1984), such as ballistocardiogram by Henderson (1905) which is the invisible vibration of body parts due to heart beat, shivering by Sherrington (1924) which is the visible vibration of the whole body, and microvibration by Rohrer (1944) which is the invisible vibration on the skin when fixing body parts. It has been considered that the generation of these mechanical rhythms have multiple factors. These mechanical rhythms showed some common characteristics as well as some special characteristics (Usui et al., 1984). The common factors for the generation are (a) the loop

system between muscle and spine (i.e., γ -motor loop), (b) the heart beat, and (c) the central nervous system. The leading factors for the respective mechanical vibrations have been reported to have different origins. For physiological tremor, it was considered to be the oscillation in the spinal reflex servo loop during the stretch of muscle (Lippold, 1957 & 1970). For ballistocardiogram, shivering, and microvibration, the leading factors are the heart beat, the activity of the central nervous system, and the γ -motor loop system, respectively. The relation between the leading factors and the other factors, however, has not been elucidated.

The historical survey of the study of physiological tremor is as follows (Usui et al., 1984). Jasper and Andrews (1938) showed the similarity between the physiological tremor and EEG (electroencephalogram), but Schwab and Cobb (1939) did not recog-

nize that relationship. At that stage of the study, the role of the central nervous system on physiological tremor was indistinct. Halliday and Redfearn (1956) pointed out that the spinal reflex was the main factor since physiological tremor existed under ischemia, but it was not recognized for deafferentation in tabetic patient, while Marshall and Walsh (1956) showed the existence of physiological tremor in the deafferentation and then denied the theory of servo-loop between muscle and spine. They proposed the mechanical model in which the muscle played the role of a low-pass filter. Buskirk and Fink (1962) reported both the existence of physiological tremor in spite of the section of the spinal cord in dog and the non-existence of physiological tremor when removing the heart of dog. They concluded that the phenomenon did not originate from the neurogenic system, but from ballistocardiogram due to heart beat. Lippold et al. (1957) recognized the correlation between physiological tremor and elementary EMG (electromyogram) and the disappearance of physiological tremor by complete deafferentation. His result was different from those of Marshall and Walsh (1964) and Buskirk and Fink (1962). He proposed the spinal reflex model based on his experiments.

Marsden et al. (1967) reported the existence of physiological tremor for the deafferented patient, and pointed out the importance of the central nervous system for its generation. Lippold (1970), however, claimed the imperfection of surgical deafferentation for other reported experiments, and insisted again on his theory based on the spinal reflex. Lippold's theory was recognized as an established theory in the 1970's until Marsden and many scholars (1978) raised objections to the explanation of pathological tremor, that is, the physiological tremor for patient, and they insisted on the important contribution of the central nervous system. Nevertheless, Gottlieb and Lippold (1983) supported steadily Lippold's theory to explain the two frequencies which were the main components in the

power spectrum of physiological tremor. However, Lippold's theory could not explain accurately the pathological tremor for central nervous disorders like in Parkinson's patients. Watanabe and Saito (1984) devised the two-reflex-loop model which was divided into the spinal level and the central nervous level in order to explain the two components of the wave. They insisted on the importance of the contribution of the central nervous system.

As stated above, various theories were subjected to controversy for a long period (Usui et al., 1984). An agreed and unified theory has not yet been devised. Therefore, one of the purposes here is to make the mechanism of physiological tremor clear. The other aim of this study is the application of the phenomenon to the evaluation of the functions of fingers with load. For that purpose, the experiment of muscular load on fingers by typing work was carried out.

METHODS

Physiological tremor was detected by piezoelectric sensor (MT-3T, Nihon Kohden) which detected the acceleration component of the mechanical vibration. The sensor was a disk type sensor: 23mm in diameter and 6.5mm in thickness, and 3g in weight. The sensitivity was an output of 100mV for 1G of acceleration: A few mV due to physiological tremor of finger were detected. The sensor was set by double faced adhesive tape on the skin between the distal interphalangeal joint of finger and the distal end of the nail (Fig. 1 (c)).

During the measurement, the subject sat on a chair, his palm resting on the board, and the finger tested was kept stretched horizontally above the hole (see Fig. 1 (b)). Visual observation of a mark helped the subject to maintain the finger in a horizontal position, while the other fingers were put on the board and the forearm was fixed by bands as shown in Fig. 1 (a). The order for the measurement of fingers was random. The measurement period for each finger was one minute. The number of

Fig. 1 Measurement of Physiological Tremor in Finger: The perpendicular bar at the tip of finger in (a) and (c) represents a marker to hold the finger in horizontal position, and the black part in (b) shows a hole.

Fig. 2 Experimental System: Respective parts show tremor sensor (MT-3T, Nihon Kohden), inserted resistance ($R=10M\Omega$), amplifier (4124type, Sanei), data recorder (1A74, Sony), integral apparatus (1322type, Sanei), and signal processor (7T17, Sanei).

subjects was ten males aged 21 to 30 years. The voltage detected by the sensor was amplified and kept in the memory of a data recorder as shown in the experimental system of Fig. 2, in which the resistance $10M\Omega$ was inserted between the sensor and the amplifier in order to adjust the voltage of the sensor's output. In the amplification, the filters were used as follows. The time constant τ was taken to be 0.3 sec., that is, the low cut frequency ($1/(2\pi\tau)$) was 0.53Hz, and the high cut frequency

was set to be 100Hz. Physiological tremor was measured both before and after load. An example of the resulting measurement is shown in Fig. 3. As working load, a training software for typing was used and the load which was 300 key hit for each finger per hour on the average was saddled for two hours. The subjects were the beginners for typing. They trained typing in advance for three hours.

We asked the subjects to answer a questionnaire both before and after load in order to evaluate subjective feelings for physical and mental fatigue. The questionnaire called as "subjective fatigue feelings", which consisted of three categories with thirty items in all, (Kogi et al., 1970) was employed.

An attempt to analyze physiological tremor was done by integration and by power spectrum. As for the data for one minute, the integral for each second was calculated by the integrator, and the mean value was obtained. The integration was apt to include noise with large amplitude in the lower frequency range of less than 1Hz. The effect of load on the evaluated integral was not recognized clearly due to the small changes of the integral values for the difference of fingers tested and for the states before and after load. Therefore, power spectrum was calculated, sampling time was 10msec. and sampling points was 512. The Power spectrum was obtained as square of the amplitude, while the integral value was the sum of the amplitude, so that power spectrum showed more clearly the different values in amplitude for different fingers, as compared with the integral value. We used mainly power spectrum in our analysis. The total power, which was defined in the study to be the sum of power spectrum for frequencies between 1.5Hz and 50Hz, was employed to evaluate the characteristics of physiological tremor of fingers and the fatigue of fingers due to load.

RESULTS AND DISCUSSION

In the first place, physiological tremor in the rest state (i.e., state before load) was measured. The

Fig. 3 Typical Example of Physiological Tremor Wave in the Index Finger for Rest State: Vertical and horizontal bars denote the calibration level of 1mV and the time unit of 1 sec, respectively.

acceleration component of physiological tremor looks like a random wave at first sight as shown in Fig. 3. The result of the integral values for five fingers is shown in Fig. 4. It indicates that the amplitude for the index finger is maximum. It also shows that the amplitude for the thumb is minimum which is half that for the index finger. The upper surface of the thumb in stretching position is not naturally in the horizontal plane, so that the vertical component of the thumb's physiological tremor is always underestimated. Therefore, the total power for the thumb becomes minimum. All results are consistent with the finding that the power spectrum has two peaks at 10 and 25Hz on the average for each finger. The existence of two peaks in power spectrum for the acceleration component of physiological tremor for the index finger has been known since Randall and Stiles (1964). One example for the five fingers is shown in Fig. 5. In general, the value of the power spectrum around 10Hz (i.e., alpha rhythm) is larger than the value around 25Hz. However, there are individual differences in the values of power spectra at the two peak frequencies. It is difficult to evaluate the characteristic of physi-

ological tremor of fingers by the peak frequencies only or by the value of the power spectrum at the peak frequencies only.

Fig. 4 Comparison of Integral Value of Physiological Tremor in the Five Fingers: Integral value for the index finger is taken as 100%. Mean value and the standard deviation for ten subjects are shown.

In this study, the total power was used as evaluational index. Relative total powers before load for the five fingers are shown in Fig. 6, and the total power before load for the index finger is being taken as 100%. The total power for index finger also denotes the maximum value. The values for

the middle and the ring fingers amount to about half that for the index finger, and the value for the little finger shows about 30% of the maximum. The value for the thumb is the minimum which is 8% of the maximum. Thus, the amount of physiological tremor varied according to the finger tested. As

Fig. 5 Typical examples of Power Spectrum of Physiological Tremor for the state before Load in the Five Fingers : Ordinate represents power spectrum. The scales per one division are 0.2, 20, 5, 2, and 0.5 (mV)² for (a) thumb, (b) index, (c) middle, (d) ring, and (e) little fingers, respectively. Abscissa represents frequency where one division denotes 10Hz.

Fig. 6 Total Power Ratio for the Five Fingers before and after 2 hrs Typing Load: The value for the index finger is taken to be 100%: Mean values for the ten subjects are shown. The marks * and ** mean the significant difference of 5% and 1% between total power ratios before and after load.

stated in the methods, the total power (Fig. 6) shows the differences between fingers more clearly than the result of integral values shown in Fig. 4. The reasons for the differences between fingers are that (a) the muscles responsible to hold a finger straightly stretched are different for each finger, and (b) the physiological tremor are influenced by the degree of control for maintaining the finger position against gravity. It is considered here that driving force for

maintaining a finger in the horizontal position originates in both the muscle-spine loop and the central nervous system. As the former loop is shorter than the latter, the higher frequency component (i.e., ca. 25Hz) is produced by the muscle-spine loop, and the lower one (i.e., ca. 10Hz) originates in the central nervous system. This point of view is in accordance with the two-loop theory presented by Watanabe and Saito (1984), but it was contrary to Lippold's theory (1970 and 1983). The ability to maintain a finger horizontally decreases with muscle fatigue, so that the total power increases due to the difficulty of controlling the finger.

In the second place, the experiment of typing for two hours was performed. The total power ratio after load is also shown in Fig. 6. The relative values of total power for five fingers after load show a similar relationship to that before load. The total power after the load for the index finger records the largest increase of about 230% as compared to the value for the index finger before load. By similarity, the values for the middle and the ring fingers denote the increase by about 180%, and the values for the thumb and the little fingers show little change. These results mean that the effect of muscular load on the index finger is remarkable, and the total power after load shows significant differences at 1% level with the value before load using t-test with paired data. The effect on the other fingers also shows a significant difference at 5% level.

Fig. 7 shows the change in frequencies for two peaks in the power spectrum for the five fingers after load as compared with the frequencies before load. The lower frequency component shifts to higher frequency. This tendency is maximum for the index finger. Also, the higher frequency component moves to the lower frequency. This tendency is also remarkable for the index finger. As for the index finger, the two peaks after load approaches each other, and the total power increases.

The value for the subjective fatigue feelings as

Fig. 7 Ratio of Mean Peak Frequency after 2 hrs Typing Load to the Value before Load, for the Two Peaks Frequency Bands and for the Five Fingers: Mean ratios for the ten subjects are shown. The level of 100% is the value before load for the respective fingers.

rated by subject before load is as negligibly small as 1%. The value for the same questionnaire after load is about 9% on the average for the physical questionnaire in the category of drowsiness and dullness, and in that of projection of physical disintegration. Especially, subjects have feelings of stiffness in the shoulders and of a tremor in the limbs after load. There is also a small number of items marked for the mental questionnaire such as difficulty in concentration. These results denote that a weak load such as typing for two hours induces mental activity rather than mental fatigue. We believe this is due to subject's interest in proceeding to the upper level in the training system for typing and he felt challenged by the load. On the other hand, physical fatigue of body parts and the whole body are remarkably visible. Therefore, the muscular fatigue for the fingers is evaluated subjectively. From these results, the change of the two peaks after load can be explained as follows: Due to the extremely small number of marks in the items of the mental fatigue,

the increase of the peak frequency in the lower frequency band means that the load by typing for two hours activates the central nervous system, while the decrease of the frequency in the higher frequency band denotes that the load deactivates the muscle-spine loop as indicated by physical fatigue.

In conclusion, the two-loop theory adopted in the study well explained the mechanism for muscular fatigue of fingers. Also, it was recognized that physiological tremor of fingers could be applied to the evaluation of the muscular fatigue.

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