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Investigation of Effects of Ways of Using Muscles on Performance of Fine Handwork

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Abstract—**To improve the performance of fine handwork, we investigated how muscles should be used in 9 examinees. A given task was how many pushpins each examinee sitting at a table was able to transfer from a dish to a taller cup in 10 seconds using a pair of chopsticks. How to use the muscles relating to the handwork was determined by measuring the electrical activities of muscles at three points such as the shoulder, the radial and ulnar sides in the forearm. Then, multiple regression analysis revealed that activation of the shoulder muscle and the aberrant ways of holding chopsticks deteriorated the performance significantly and also that activation of muscle on the ulnar side (little finger side) in the forearm and the normal and near-normal ways of holding chopsticks improved the performance significantly. In conclusion, to improve the performance or to show one's full abilities, it is important to hold and handle a tool very gently by relaxing the shoulder, thumb and forefinger as much as possible during fine handwork.**

I. INTRODUCTION

THE first author of this paper has been developing the Scrub Nurse Robot (SNR) in the Human Adaptive Mechatronics (HAM) project of Tokyo Denki University [1-7]. The SNR was designed to compensate for severe shortage of human scrub nurses, who help surgeons in operating rooms by providing surgical instruments and keeping them tidy and in order.

One of the main problems in the development of SNR is to solve how the SNR should adapt to individual surgeons with different skills. As the first step to answer this problem, we have been databasing the sequence and frequency of surgical instruments used by individual surgeons in a particular surgical operation because these data reflect their skills and experiences.

How to measure operators' skills has been a main topic in HAM. One major approach to this topic is to measure the time spent finishing a task [8-10]. This approach determines an operator's skill from a viewpoint of speed. It is very important for individual operators to try to improve their skills constantly, and the constant efforts will be reflected by increase in speed of finishing the task. Therefore, measurement of the speed is the most reasonable approach.

We have also been interested in surgeon's skills from a different viewpoint. This view derives from a common belief that a considerable mental pressure impedes full exertion of human skills. More specifically, in the case of handwork it is generally said that mental pressure increases muscular tone in the shoulders and upper extremities so excessively that humans can not use their hands and arms smoothly. Since the first author in this study has experience as a cardiovascular surgeon, who needs fine manipulation of surgical instruments, he learned and experienced that it is crucial to hold surgical instruments very gently by relaxing the shoulder, thumb and forefinger as much as possible when handling the instruments.

Therefore, we formed a project to investigate the effects of surgeon's mental pressure on their manual dexterity.

II. AIM

As the first step toward the above-mentioned goal, we mainly focused on activities of muscles relating to handwork in this study, because mental pressure is extremely difficult to determine properly.

III. MATERIALS AND METHODS

Nine healthy volunteers were enrolled as examinees in this study. In each examinee, we measured electromyograms (EMGs) of three positions in the dominant shoulder and forearm during a given task using a pair of chopsticks. The EMG (electrical activities of muscle) was used as an estimate of mechanical activities of muscle such as muscular tones or forces, because measurement of muscular forces is invasive and much more difficult and because it is well known that EMG has a good correlation with muscular tones or forces in a particular muscle of a person.

A. How to measure electromyograms

The trapezium muscle was selected as a representative of muscles moving each examinee's dominant shoulder (Fig. 1a). Two positions in the forearm were selected in the following way. When the thumb and forefinger were used or bent together strongly, the position where underlying muscles were most visibly contracted was selected (Fig 1b), and this position normally corresponds to the skin over the flexor carpi radialis muscle. In the case of bending the third and little

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fingers, the same procedure was repeated to find the best position and flexor carpi ulnaris muscle is thought to be usually selected (Fig. 1c). To measure muscular activities of these positions, the active and indifferent surface electrodes were placed on the skin over each muscle shown in Fig. 1.

Simultaneously, electrical activities of the heart (electrocardiogram: ECG) were recorded to estimate sympathetic nervous activities since mental pressure can activate the sympathetic nervous system and this activation can result in an increase in heart rate (heart beats per minute). Therefore, a change in heart rate can be used as an index of a change in mental pressure. The positions of electrodes were finally determined as shown in Fig. 1 in order to reduce noises as much as possible and avoid interference between electrocardiography and electromyography.

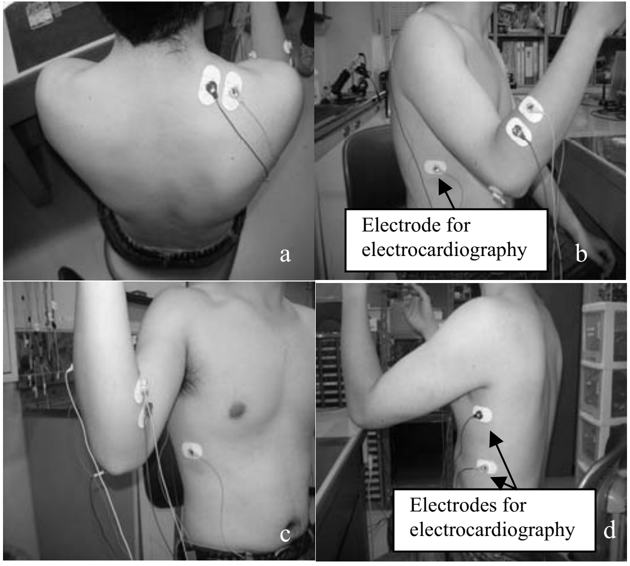

Fig. 1. Positions of electrodes measuring electromyogram and electrocardiogram (ECG)
a: the skin over the trapezium muscle, b: the radial side of forearm, normally related to the flexor carpi radialis muscle, c: the ulnar side of forearm, normally related to flexor carpi ulnaris muscle, d: electrodes for electrocardiogram

Both electrical activities amplified 1,000 times by an amplifier (BA1104-M, Teac Instruments) were sent to a personal computer through a telemetric device (BA1104-M, Teac Instruments) and an AD converter (MP150, BIOPAC Systems). Thereafter, both signals were measured at a sampling frequency of 5,000 Hz with the software AcqKnowledge 3.8.1 (BIOPAC Systems) installed in the PC.

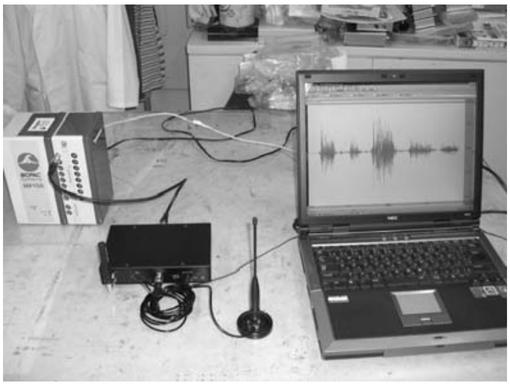

Fig. 2. Devices to measure and analyze EMG and ECG
Electrical activities obtained from muscles and heart were sent by telemetry to a personal computer through an AD converter.

The scene of the experiment was videotaped with a digital video camera to check the experiment visually later.

B. Given Task

A given task in this study was how many pushpins each examinee was able to pick up and transfer from a laboratory dish to a cup using a pair of chopsticks in 10 seconds (Fig. 3). Since the chopsticks were varnished, it seemed considerably difficult to pick up and transfer pushpins. The distance between the centers of both containers was fixed to 15 cm, and each examinee was not allowed to put the forearm or elbow on the table.

We evaluated the performance in this task in the following ways. We defined ‘Frequency of Trial’ as the number of pushpins which each examinee picked up successfully in 10 seconds, and ‘Frequency of Success’ as the number of pushpins which they picked up and transferred to the cup successfully in 10 seconds. If each examinee drops one pushpin after he has picked it up, this is counted as one trial but no success.

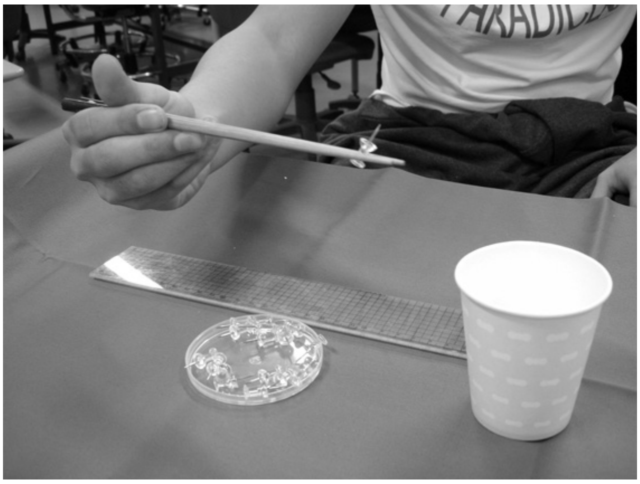

Fig. 3. A scene of an examinee’s conducting a given task: how many pushpins an examinee is able to transfer from a laboratory dish to a taller cup using a pair of chopsticks in 10 seconds

This experiment consisted of two phases: Phase ‘practice’ and Phase ‘test’. Phase ‘practice’ was provided in order for each examinee to get used to this considerably difficult task, and we told each examinee to try to relax themselves and made an untrue announcement that we would not obtain any data during Phase ‘practice’. Before the start of Phase ‘test’, we intended to behave so that each examinee would feel pressured. Each examinee repeated the above-mentioned task10 times in each phase.

C. How to analyze electrical activities

One example is shown in Fig. 4. The waveform at the top row is the EMG obtained from the radial-side (thumb side) muscle in the forearm, the waveform at the second row from the ulnar-side (little-finger side) muscle, and the third one from the shoulder muscle. The fourth waveform is a raw ECG and its smoothed waveform is shown at the bottom row.

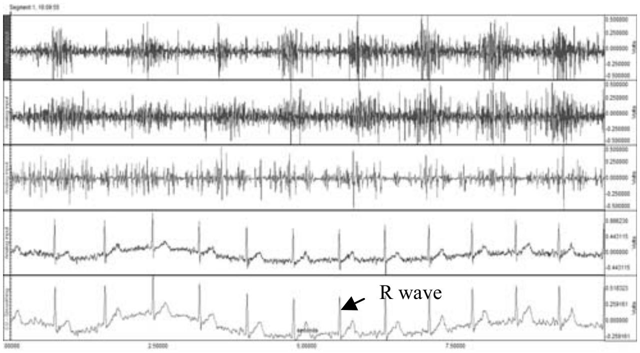

Fig. 4. An example of EMGs and ECGs
Top: EMG from the radial-side muscle in forearm, Second: EMG from the ulnar-side muscle in the forearm, Third: EMG from the shoulder muscle, Fourth: raw ECG, Bottom: the smoothed ECG. The arrow indicates an R wave.

In the case of EMG, root mean square (RMS) of a 10-second EMG was calculated and used as a representative index of muscular activities during each task (10 seconds). Because large R waves in ECG were observed as shown in Fig. 4, the EMG might be contaminated with them. We, therefore, excluded the EMG signals synchronized with the R waves from calculation of RMSs of muscular activities. The RMSs calculated from EMGs in the radial-side muscle, ulnar-side muscle and shoulder muscle were termed 'RMS-R', 'RMS-U' and 'RMS-S', respectively.

In the case of ECG, an average heart rate was calculated from the 10-second data.

D. Categorizing How to Hold a Pair of Chopsticks

Nine examinees were categorized into 4 types in the ways of holding chopsticks: six examinees as the normal type and the other three as three different types.

In the normal way, the left pair shown in Fig. 5 is held with three fingers such as thumb, forefinger and middle finger and the other pair is held between the base of thumb and the lateral side of third finger. When something is picked up with chopsticks, the pair held with three fingers is mainly moved, therefore usually termed 'dynamic pair'. By contrast, the other pair held between the thumb and third finger is hardly moved and therefore called 'static pair'. The 'normal' type, termed Type 'normal', is said to be the most effective and efficient way of holding chopsticks.

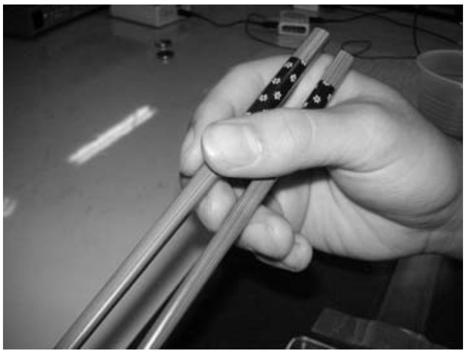

Fig. 5. Normal type of holding a pair of chopsticks
Termed Type 'normal'

Compared to Type 'normal' shown in Fig. 5, Fig. 6 demonstrates one examinee's way of holding chopsticks. This type may seem normal, but is different in the way of holding the dynamic pair. It is mainly held just between forefinger and middle finger. This type is thus characterized by not using the thumb so much when something is pinched with chopsticks. So, this type is named Type 'not-using-thumb' for convenience sake in this paper.

Fig. 6. An aberrant type of holding chopsticks
Named Type 'not-using-thumb'

The second aberrant type is shown in Fig. 7. The dynamic and static pairs are closely held (termed Type 'closely-held'). Since the interval between two pairs is narrow, it seems difficult to pick up something relatively large.

Fig. 7. Second aberrant type of holding chopsticks
Named Type 'closely-held'

Fig. 8. Third aberrant type of holding chopsticks
Named Type 'crossed'

The last aberrant way of holding chopsticks is demonstrated in Fig. 8. The dynamic and static pairs are crossed (termed Type 'crossed'). This type seems the most difficult case to use chopsticks effectively. The two pairs possibly have to be moved actively in order to pick up something.

E. Statistical Analysis

Statistical analyses were carried out using software JMP 7.0 (SAS Institute). P values less than 0.05 are assumed to be significant.

IV. RESULTS

The given task was repeated 10 times in each examinee during both Phases 'practice' and 'test', but one task in an examinee during Phase 'test' was excluded from analysis because the data were not accurate. Therefore, the total numbers of tasks were 90 and 89 during Phase 'practice' and 'test', respectively. Univariate and multivariate analyses were made.

A. Comparison Between Phases 'Practice' and 'Test'

The data are listed in Table I.

TABLE I
COMPARISON BETWEEN PHASES 'PRACTICE' AND 'TEST'

	Practice (N = 90)	Test (N = 89)
Freq. of Trial	7.48 ± 1.76	7.70 ± 2.06
Freq. of Success	6.91 ± 1.97	7.08 ± 1.98
Heart rate (bpm)	78.0 ± 9.2	79.8 ± 10.6
RMS-R	0.106 ± 0.042	0.127 ± 0.044
RMS-U	0.124 ± 0.041	0.112 ± 0.051
RMS-S	0.066 ± 0.046	0.066 ± 0.046

Mean ± standard deviation

Freq. of Trial: Frequency of Trial, Freq. of Success: Frequency of Success

1) Frequencies of Trial and Success

Frequency of Trial was defined as the number of pushpins which each examinee picked up in each task (or in 10 seconds), and Frequency of Success as the number of pushpins successfully transferred in 10 seconds.

Frequencies of Trial and Success during Phase 'practice' were 7.48 ± 1.76 (mean ± standard deviation; N = 90) and 6.91 ± 1.97 (N = 90), respectively. On the other hand, during Phase 'test', they were 7.70 ± 2.06 (N = 89) and 7.08 ± 1.98 (N = 89). These two frequencies just slightly increased in Phase 'test', but no statistically significant difference was observed between the phases (NS, Student's t-test).

2) Heart rate

The heart rate was 78.0 ± 9.2 and 79.8 ± 10.6 beats/min during Phases 'practice' and 'test', respectively. The heart rate in Phase 'test' increased by 1.8, but there was no statistically significant difference (NS, Student's t-test).

3) RMSs of EMG

All the RMSs of EMGs obtained from three positions were not statistically significant between the two phases (NS, Student's t-test).

B. Correlations

Correlations were examined between any two continuous variables such as RMS-R, RMS -U, RMS –S, heart rate and Frequencies of Trial and Success. The results are listed in Table II. The phenomenon known as collinearity is likely to occur when two variables of Frequencies of Trial and Success are introduced into independent variables of multiple regression analysis because their correlation coefficient (0.87) is more than 0.80. The other combinations are unlikely to cause the problem.

TABLE II
CORRELATION COEFFICIENTS

	RMS -R	RMS -U	RMS -S	HR	Freq. of Trial	Freq. of Success
RMS-R	1.00	0.75	0.68	-0.42	0.53	0.39
RMS-U	0.75	1.00	0.65	-0.30	0.57	0.54
RMS-S	0.68	0.65	1.00	-0.29	0.39	0.33
HR	-0.42	-0.30	-0.29	1.00	-0.46	-0.30
Freq. of Trial	0.53	0.57	0.39	-0.46	1.00	0.87
Freq. of Success	0.39	0.54	0.33	-0.30	0.87	1.00

HR: heart rate.

C. Multiple Regression Analysis

1) Frequency of Trial as Dependent (Response) Variable

We analyzed which factor variables explained the results of Frequency of Trial significantly using multiple regression analysis. The independent variables chosen here were heart rate, RMS-R, RMS-U, RMS-S, the types of holding chopsticks and the experimental phases of 'practice' and 'test'. Because the holding types and experimental phases

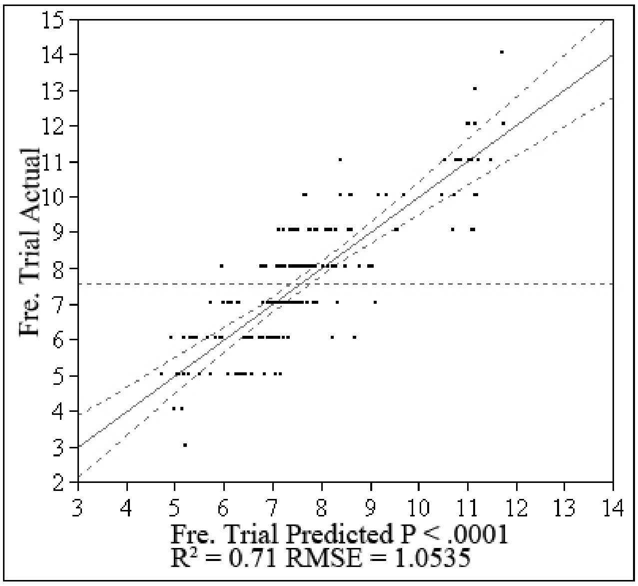

Fig. 9. Leverage plot of whole model for "Frequency of Trial" This plot indicates the relation between the actual values for Frequency of Trial and the values predicted by the regression model. The independent variables other than the experimental phases ('practice' or 'test') were statistically significant. These significant variables explain 71% of the variation in Frequency of Trial.

were not continuous but categorical (nominal), they were converted into quantitative variables (dummy variables) by using dummy coding [11].

The multiple regression model for Frequency of Trial is shown in Fig. 9 and Table III. The plot shown in Fig. 9, termed a leverage plot, shows how the data fit the model. Namely, it indicates the relation between the actual values for Frequency of Trial and the values predicted by the regression model. The diagonal straight line is the regression line (line of fit) for the whole model. The curve around the line of fit is the 95% confidence curve. If the curve cross the horizontal reference line (the dotted line in Fig. 9), then the effect is significant. The value for R^2 (coefficient of determination) reports that 71% of the variation in the actual Frequency of Trial can be absorbed by fitting the model.

TABLE III

PARAMETER ESTIMATES IN MULTIPLE REGRESSION ANALYSIS FOR FREQUENCY OF TRIAL

	Estimated Coefficient	Standard error	t value	p value
Intercept	-0.314759	1.32408	-0.24	0.8124
RMS-R*	7.6984884	3.273637	2.35	0.0198
RMS-U*	11.700491	2.730107	4.29	<.0001
RMS-S*	-9.6756	2.682055	-3.61	0.0004
Heart rate*	0.0774286	0.014936	5.18	<.0001
Type [closely-held]*	-3.54527	0.331782	-10.69	<.0001
Type [crossed]*	-0.877185	0.240175	-3.65	0.0003
Type [not-using-thumb]*	4.0908279	0.326803	12.52	<.0001
Type [normal]*	0.331627	0.139651	2.37	0.0187
Phase [practice]	0.0129909	0.080717	0.16	0.8723
Phase [test]	-0.012991	0.080717	-0.16	0.8723

* denotes that the variable followed by * is significant.

Out of the chosen independent variables, only the variable which categorized the experimental phase into ‘practice’ or ‘test’ was not significant. As factors to increase Frequency of Trial, the RMSs of EMG in the muscles in the forearm, heart rate and the types of holding chopsticks such as Types ‘normal’ and ‘not-using-thumb’ were found. Type ‘not-using-thumb’ is not completely normal, but quite similar to Type ‘normal’ (Fig. 6).

By contrast, the RMS of the trapezium muscle (shoulder muscle) and the ‘closely-held’ and ‘crossed’ types of holding chopsticks reduced Frequency of Trial. In other words, more tense activities in the shoulder muscle and the ways of holding chopsticks distant from Type ‘normal’ reduced Frequency of Trial.

2) Frequency of Success as Response (Dependent) Variable

The multiple regression model for Frequency of Success showed a smaller coefficient of determination (R^2 0.56) than the regression model for Frequency of Trial. In this analysis, the RMS from the muscle on the thumb-side in the forearm was no longer significant. Whether the task was carried out in Phase ‘test’ or Phase ‘practice’ was not still significant, and the other variables were still significant.

Like the multiple regression analysis for Frequency of Trial, the variables to increase Frequency of Success were the RMS of EMG in the ulnar-side (little-finger side) muscle in the forearm, heart rate and the types of holding chopsticks such as Types ‘normal’ and ‘not-using-thumb’. In contrast, the same three variables as in Frequency of Trial decreased Frequency of Success: the RMS of the trapezium muscle (shoulder muscle) and the ‘closely-held’ and ‘crossed’ types of holding chopsticks.

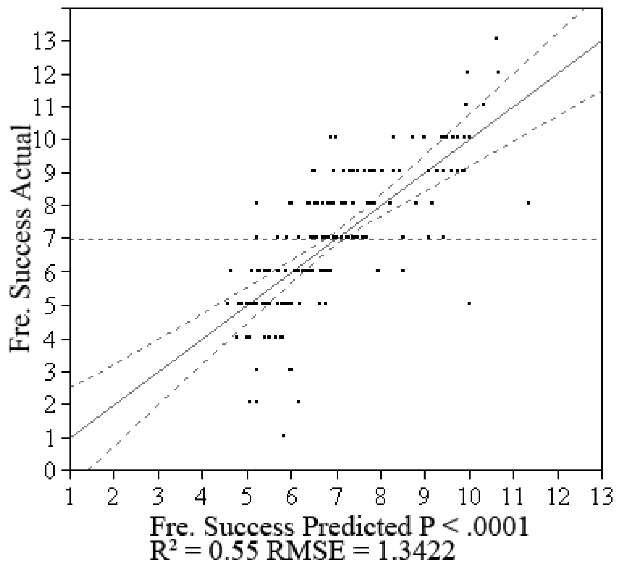

Fig. 10. Leverage plot of whole model for “frequency of success” The independent variable ‘RMS-R’ was no longer statistically significant, and the experimental phase (‘practice’ or ‘test’) was not still significant. Significant variables explain 55% of the variation in the frequency of success.

TABLE IV

PARAMETER ESTIMATES IN MULTIPLE REGRESSION ANALYSIS FOR FREQUENCY OF SUCCESS

	Estimated Coefficient	Standard error	t value	p value
Intercept	-2.107799	1.6867	-1.25	0.2131
RMS-R	-3.312667	4.170173	-0.79	0.4281
RMS-U*	20.213761	3.477788	5.81	<.0001
RMS-S*	-7.746704	3.416576	-2.27	0.0246
Heart rate*	0.0952271	0.019027	5.00	<.0001
Type [closely-held]*	-3.395436	0.422646	-8.03	<.0001
Type [crossed]*	-0.887979	0.30595	-2.90	0.0042
Type [not-using-thumb]*	3.7300743	0.416303	8.96	<.0001
Type [normal]*	0.5533402	0.177897	3.11	0.0022
Phase [practice]	0.0617091	0.102822	0.60	0.5492
Phase [test]	-0.061709	0.102822	-0.60	0.5492

* denotes that the variable followed by * is significant.

V. DISCUSSIONS

The results of multiple regression analysis indicate that increase in muscular activities of the shoulder deteriorates the performance of fine handwork, but increased activities in the ulnar-side muscle in the forearm improve the performance. These results can provide scientific evidence to the first author’s personal experience such that it is crucial to hold surgical instruments very gently by relaxing the shoulder, thumb and forefinger as much as possible when handling the instruments. In other words, it is important to rather use the little finger and the third finger than the thumb and the forefinger although this expression may be misleading. This knack or secret may improve human skill in fine handwork using a tool, and their current abilities can be fully displayed by being constantly conscious of relaxing shoulders, thumb and forefinger.

In addition, the number of pushpins moved from a laboratory dish to a cup in 10 seconds was significantly influenced by the ways of holding chopsticks. The ‘normal’ type and type similar to the ‘normal’ result in better performances, and the aberrant types distant from the ‘normal’ type worsen the performances. In this study, we had 6 examinees for Type ‘normal’ but only one examinee for each of three aberrant types. Therefore, we could not deny the possibility that unknown individual factors other than the aberrant types might have brought the above-mentioned effects in multiple regression analysis. Moreover, we have not investigated difference between the ‘normal’ type of holding chopsticks and the other aberrant types from the viewpoint of mechanics or have not found any references dealing with this topic. However, we believe that those effects of ways of holding chopsticks on the performance of the given task seem very reasonable.

We measured the heart rate in this study as an index of mental pressure. Assuming that the results of heart rate only reflect the degrees of mental pressure, we have to conclude no significant difference in mental pressure between the two experimental phases because of no significant change in heart rate. However, there are three possibilities concerning the degree of mental pressure. One is that there might have been already some mental pressure put on examinees from the beginning of the practice phase. Another possibility is that no significant mental pressure might have been loaded on the examinees throughout the experiment. For the last possibility, some were relaxed and the others pressured. The absolute values in average heart rate were higher than those generally observed when humans are fully relaxed, but lower than those when humans are under high mental pressure.

In general, the heart rate rises when sympathetic nervous system becomes dominant. Like a famous example such as ‘runner's high’ in jogging, which is explained to result from excretion of endogenous opioids, runners are not likely to be under mental pressure, but actually their heart rates increase. In addition to this comfortable exercise, the sympathetic nervous system can be activated when humans are highly motivated in doing something.

We checked the changes in heart rate and the scenes of the experiment in each examinee. Then, we concluded that some examinees might have been under considerable mental pressure from the beginning, others might have been highly motivated, and the others might have been relaxed throughout the experiments. Thus, we realized that it is extremely difficult to put the same degrees of mental pressure on all examinees because whether they feel pressured or not or how much pressure they feel depends very much on individuals even if they are put under the same conditions.

To go further, two major formidable problems remain to be solved: how to measure mental pressure accurately and how to put mental pressure surely.

VI. CONCLUSION

This study suggests that being constantly conscious of relaxing the shoulder, thumb and forefinger can show one’s full abilities, thereby probably demonstrating the best performance in handwork.

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