Study on the Appraisal System of Manual Work Efficiency

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ABSTRACT

The biomechanics and physiology of the joints, muscles, sensors and nerves of the hand, as well as the manual work were analyzed in detail. In addition to 65 minor indexes, 5 major ones including the strength, fatigue, range of motion, tactility and dexterity were proposed in order to evaluate the manual work efficiency. Different approaches and facilities corresponding with varied indexes aiming to appraising the efficiency were designed and manufactured. With the aid of these apparatus, 26 subjects participated in the tests which were relative to 5 major and 47 minor indexes. Based on the experimental results, an optimal appraisal system integrating with some indexes employed in the work efficiency assess were presented. Also, the optimal efficiency appraisal system's practicality was verified by the evaluation of heat resistant gloves.

Keywords: Manual Work, Efficiency, Appraisal

INTRODUCTION

Generally, many factors, such as the temperature, work proficiency, work conditions, the psychology, etc. affect the efficiency of manual work. Therefore, the influence due to these factors over the manual work must be taken into account when designing efficient instruments and facilities(Seong,1999), operating in the cold environment(Ronald, 1995)and Extravehicular Activity(EVA)(O'Hara et al, 1988; Ram et al, 1995; Melissa et al, 2001)and so on.

A systematic appraisal method for manual work was proposed by O'Hara (1988) when studying the effects of EVA gloves on manual performance. He divided the manual work efficiency into 5 aspects: strength, fatigue, range of motion (ROM), tactility and dexterity. Many scholars have conducted further studies on the evaluation systems and methods. Duque et al (1995), Frederick et al (1995), Raymond et al (2001), Fowler et al (2001)discussed the grip and pinch of hand. Melissa (2001) studied the ROM with the aid of the data glove. Tommy (1995), Nina (1997), Jouni et al (2002) described how to estimate and measure the fatigue during exercise. Ram et al (1994) revealed that tactility could be characterized as a function of grasp force. Ronald et al (1995), Muralidhar et al (1999), Arunkumar et al (2003) studied the relationship between dexterity and the anatomical structures such as muscle, nerve system, joints and ligaments. Hwa -S. Jung et al (2010) discussed handle position for boxes with different sizes and manual handling positions. There still are, however, problems associated with the actual manual work, for instance, the

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relation between the efficiency appraisal system and the manual work and physiology, the standardization of the efficiency appraisal methods, and the best index and method's choice, etc. They are necessary for the design and evaluation of EVA spacesuit glove, and also pressed for in some other gloves, work efficiency appraise under the especial environment (such as environmental hypoxia, underwater, polar region, etc.), research work on manipulator, work efficiency design of appliances, and so on. Therefore, the objective of this paper is to clarify the relationship between the work efficiency indexes and physiology and operational contents. In addition, the paper will set up a complete and systematic efficiency appraisal system, build up the optimum appraisal system for the manual work by means of testing and analyzing each individual index. Furthermore, a theoretical foundation for designing logical appraisal methods will be proposed here.

Nomenclature

ABP	abductor pollicis
ADP	adductor pollicis
APB	abductor pollicis brevis
APL	abductor pollicis longus
ECB	extensor carpi radialis brevis
ECL	extensor carpi radialis longus
ECU	extensor carpi ulnaris
ED	extensor digitorum
EDM	extensor digiti minimi
EI	extensor indicis
EPB	extensor pollicis brevis
EPL	extensor pollicis longus
ES	extensor slip
FCU	flexor carpi ulnaris
FCR	flexor carpi radialis
FD	flexor digitorum
FDP	flexor digitorum profundus
FDS	flexor digitorum superficialis
FPB	flexor pollicis brebvis
FPL	flexor pollicis longus
IP	inter-phalangeal
LU	lumbricals
MCP	metacarpo-phalangeal
MI	musculi interossei
PL	palmaris longus
PIP	proximal interphalangeal

THE PHYSIOLOGICAL ANALYSES

The relationship between the manual work efficiency indexes and the physiology and operational contents is very close. This chapter will describe the relationship in detail. Next chapter will specifically demonstrate the efficiency appraisal system in combination with the work contents.

Strength

The strength of the hand is primarily created by the traction of finger sinews caused by the contraction of the forearm muscle. With the exception of the thumb, the flexion of all fingers is dominantly generated by the relevant muscles divided into four slices by sinews. There are two tendons (FDP and FDS) at the palm side of each finger. Tendon FDP connects with the phalange of fingertip. The flexion strength of the fingertip is mainly produced by this tendon. Tendon FDS ends at the both sides of the middle phalange of fingers. Its traction combined with that of FDP forms the flexion strength of the middle of fingers. The flexion strength of finger root comes from the combination of FDS, FDP, LU and MI. But LU and MI are weaker than that from FD. As the phalanges of a finger linked to the joints, the traction of each muscle is manifested by the combined moments of each section.

The thumb is different from all the other fingers. It has independent flexural and extending muscles connected with the forearm. Due to there are more muscles connected with the thumb, the directions of the thumb movements are more complicated, and the maximum strength is great than those of other fingers.

According to the principle of strength-generating, strength can be classified into transient maximum strength and maximum lasting time in the same strength. So, the indexes of manual work with respect to each muscle are the maximum strength and the fatigue. Consequently, grip, pinch and screw can be adopted to appraise the maximum strength and fatigue leaded by muscle movements.

Range of Motion （ROM）

The movements of the hand and the fingers are circumvolving around the joints. However, under the constraints of ligaments and tendons, ROM of the hand is greatly limited. As the result, ROM is the one of the important indexes to appraise the manual movements.

The muscles that connect to the thumb include ABP、FPL、FPB、APB、APL、EPL and EPB, and so on. It is such muscles that make thumb have a larger ROM than other fingers, and the ROM needs to be appraised based on the angle of 3-dimensional maximum range.

Those connecting to the other fingers are muscles such as FDS、FDP、EDM、EI and ED, etc. ROM of the other fingers approximately locates within a plane, and can be assessed using the angle of a 2- dimensional maximum range. In addition, the strength of the other fingers partly comes from the same muscle, therefore, it may arises that one finger will follow other fingers bending. This fact also needs to be taken into consideration in the appraisal.

The muscles that connect directly to the wrist are ECL、ECB、ECU、PL、FCR and FCU, etc. These muscles enable the wrist to have 3- dimensional ROM, which needs to be appraised by the angle of a 3- dimensional maximum range.

Perception

Perception is controlled by the nervous system, which consists of the sensors nerves, brain and executive mechanism. There are mainly two types of sensors: (1) the deep sensors, where strength and posture etc. can be sensed, and (2) surface sensors, where pain, tact, cold and heat can be apperceived. Every finger has four nerves which send signals from the sensors to the brain. After operating the signals, the brain dominates the movements of the hand to finish the manual work through executive mechanism.

In regard to the nervous system, the appraisal index of the manual work is a tactile perception and it could be appraised from the sense of strength, length and shape, etc.

Dexterity

To finish manual work, collaboration among muscles, tendons, and the nervous system is required. Regard the composite usage of biological functions of the hand, the composite appraisal index of manual work is dexterity. This can be evaluated by the dexterity between fingers, between fingers and wrist and between hands. Moreover, the dexterity is closely related to training, mentality, types of work and the environment of work.

THE ANALYSIS OF MANUAL WORK EFFICIENCY

Due to the complexity of manual structures and physiology and work, the test appraisal system of manual work efficiency contains three levels similar to O'Hara's (table 1). The first level is the direct work which relates to physiological system; the second one is the complex work of the composite of physiological system and the third level is the integration work which conducts the actual work. However, in this paper fatigue is still in the first level. This is because fatigue is also an exhibition of the muscle strength. In addition to this, the appraisal system has made some improvement based on O'Hara's system. The relation between appraisal indexes and the physiological and operational contents has also been clarified. This makes it possible to select the optimal indexes and test methods.

Strength

According to the biomechanics and operational contents of the hand, the major functions of the hand involve the grip, take, pinch, turn and twist etc. For the sake of simplifying and systemizing the problem, these functions can be divided into grip, pinch and screw (table 1) in terms of the operational strength.

Grip

Grip is the strength generated during the adducent process of all fingers. In accordance with the different hand positions, grip is divided into three types: grip supination, grip pronation and grip level-palm. According to the positions of hand dynamometer, grip is also divided into three sorts: fingertip grip, the middle of fingers grip and finger root grip. These classifications were not considered in the work conducted by O'Hara (1988), Duque et al (1995), Frederick et al (1995) and Raymond et al (2001). Fingertip grip consists mainly of the adduction of FDP; the key part of the middle of fingers grip is the composition of the forces of FDS and FDP; finger root grip basically contains the resultant force of LU, MI, FDS and FDP, etc. Combining above two classifications together, there are nine different types of grips.

Pinch

Pinch indicates the force generated by the adduction of five fingertips in one hand. There have 4 different pinches according to the functions of the thumb and other four fingers. These are the pinches of thumb and index finger, thumb and middle finger, thumb and ring finger, thumb and little finger. Furthermore, there are two other common pinches: the pinch of thumb, index finger and middle finger; the pinch generated by putting thumb in the middle of index finger (all the other fingers help index finger). Based on the poise of hands, pinch can be catalogued into pinch supination, pinch pronation and pinch level-palm. As the result, there are 18 kinds of hand pinches which are more integrated than the research of Swanson et al (1970) and Fowler et al (2001).

Screwing

To our best knowledge, there are few of reports focusing on screwing presently. It is that the fingertips press the object firstly and then screw object. In addition to flexors which are connected to the hand, and the muscles of hand participate in the work. It generates the torque to accomplish work and relates to the object's friction coefficient. So one of the most accurate describing ways of screwing is torque. According to the fingers involved in the work, screwing torque can be classified into: the screwing torque among thumb and index finger and middle finger; the screwing torque between thumb and index finger and the screwing torque among all fingers. In according with the poise of palms, the screwing torque can be classified into: screwing torque supination, screwing torque pronation and screwing torque level-palm. Therefore, there are 9 different types of screwing torque of the fingers.

Fatigue

After a long period of work with certain forces, the muscle feels fatigued so that it cannot continue achieving the work and needs some time to recover. Fatigue directly relates to the strength employed in work and the time of work. In other words, it is in conjunction with deferent power. In addition, fatigue cannot be defined as a strict standard (Nina, 1997 et al; Bigland-Ritchie et al, 1986; Edwards, 1981) and it also relates to mentality (Shingo et al, 2001; O'Hara et al, 1988). In regard to strength types, fatigue can be classified into grip fatigue, pinch fatigue and screwing fatigue. Ram (1995), O'Hara et al (1988), Bigland-Ritchie et al (1986) and Edwards (1981) only predigested fatigue to grip fatigue.

Grip fatigue is the strength of all fingers except for the thumb and it mainly tests on the fatigues of FDP and FDS. Pinch fatigue mainly tests FDP, but apparently the total strength of other fingers is stronger than that of the thumb. So pinch fatigue in fact tests the fatigue of the muscles relative to the thumb. Screwing is the combination of the press of fingers and screwing object. It results from the collaboration of the muscles involved in grip and pinch as well as hand muscles. This is the integrated test on manual muscle fatigues (table 1).

ROM

During manual work, it is impossible to touch directly all the spots around the wrist. It has certain ranges. Normally, there are two types of ROM: (1) passive ROM, where the external forces are applied; and (2) active ROM, where the subject applies maximum strength to obtain. Obviously, in regard to the manual work, the passive ROM is of little help. So in this paper we discuss the maximum active ROM by hand. On the basis of the hand anatomical structure, ROM can be sorted mainly into thumb, other fingers and wrist (table 1). There is not any theoretical classification of ROM in the previous studies proposed by O'Hara (1988) and Melissa (2001).

Thumb

Unlike other fingers, the thumb ROM is more complicated. It is similar to a taper. Its ROM can be classified into: MCP1 extension, PIP1 extension, MCP1 flexion, PIP1 flexion and thumb side extension (Fig. 1.1~Fig. 1.3). O'Hara (1988) did not take thumb side extension into account.

Other fingers

The relevant tendons connect by means of the same muscle, so all of the other four fingers, when one of the fingers bends, the other three fingers often bend consequently. The Index finger is more independent compared to the other three fingers. For the other three, this phenomenon is very significant. Therefore, according to the anatomical structure, ROM can be classified into MCP extension, MCP flexion, PIP extension, PIP flexion, PIP3 flexion and PIP5 flexion (Fig. 1.4～Fig. 1.7). Flexion of the knuckles of the middle finger and the little finger are seldom used in actual work. That is why O'Hara (1988) did not include these two indexes. Due to the particularity of the index finger flexion, index finger ROM is added: PIP2 flexion and the maximum angle between index finger and middle finger (Fig. 1.8~Fig. 1.9).

Wrist

As a taper, wrist motion often is catalogued into wrist flexion, wrist extension, ulnar deviation, deviation and radial deviation depending on the different bending direction (Fig. 1.10~Fig. 1.13; O'Hara, 1988; Laura, 2003).

Tactile perception

Differing from O'Hara (1988), Ram (1994) and Bishu (1995)'s work, tactile perception here is classified into strength perception, length perception and shape identification （table 1）, in order to evaluate tactile perception more systematically.

Strength perception

Strength perception can be classified into the existence of strength perception and the changes of strength perception. The former is to sense the existence of strength; and the latter is to sense the change of strength. O'Hara's (1988) researches only considerate the latter. While the hand is working, strength is perceived by surface sensors, it is then transmitted to the brain by nerves. After judging the contents from the sensors, the brain then gives orders to the hand, and only at this stage can the hand take next action. During this process, the existence of strength perception is the first step in manual work and it is also the precondition of all work. For example, if you want to get an object, firstly you have to perceive the object exists, then the hand can take action. Otherwise the hand will continue to extend forward. In fact, when an object is sensed, there is strength acting on the hand and it has been perceived.

When sensors perceive the existence of strength, they can also perceive the change of strength. It is important for the brain to judge correctly. For example, astronaut can use a larger amount of strength to get an object, but this wastes strength. The best way to do this is to get the object using just the right amount of strength. This requires the hand to sense the change of strength accurately.

Length perception

According to the concept of length, the length perception can be classified into two-point discrimination and the change of length perception. Two-point discrimination is to sense the existence of two-point in space by fingers; the change of length perception is to feel the change of the distance of two spots. Two-point discrimination is the typical test of length perception index， O’Hara (1988) and Bishu(1993) only focused on this.

Shape identification

The shape identification is the collaboration of the different perceptible signs in brain, in which strength perception and length perception operate the important action. The different sensors of the hand sense the various dynamic signs operating on the hand, when hand gets the object and continually turns it. The brain can judge the object shape by synthesizing all the signs.

Dexterity

Dexterity is the integrated appraisal index. Not only does it integrate strength, fatigue, ROM and tactile perception, but it also includes factors such as mentality, training and the skillfulness of work. The major difference between dexterity and the other indexes is that better or worse dexterity affects work efficiency directly. So all the tests on dexterity are associated with time.

According to the different parts of hand which is involved in work, dexterity can be classified into dexterity among fingers and dexterity between hand and other parts. Dexterity between fingers can be classified into: dexterity between thumb and index finger; dexterity among thumb, index finger and middle finger; dexterity among all fingers (Table 1). Dexterity between hand and other parts can be classified into: dexterity between wrist and hand; dexterity between two hands (Table 1). Many researchers such as Ronald et al (1995), Muralidhar et al (1999) and Arunkumar et al (2003) designed various tests to evaluate dexterity, but no one has taken further step to classify dexterity and stated the dexterous relations among different parts of hand.

TEST DESIGN

Strength

The tests on grip and pinch are simple. Both the different grip and pinch can be measured by dynamometer. Due to screwing torque relates to friction coefficient, its magnitude is based on the friction coefficient and the size of the test object (Fig. 3.1).

Fatigue

Because there is no strict standard to define the fatigue of muscles, the appraisal of fatigue is the most complex of all the appraisals of hand abilities. Hand fatigue can be evaluated from 3 different aspects: physiological muscle fatigue, subjective fatigue and performance decline fatigue. Physiological muscle fatigue has to use physiological test apparatus to define. However, it is really difficult to use such apparatus in practical work efficiency appraisal, the apparatus will affect efficiency appraisal, such as the spacesuit glove, and the physiological muscle fatigue has not well-pleasing standard, so in this paper the subjective fatigue and the performance decline fatigue are applied to test. In addition, in actual work, fatigue results from screwing nuts or working while wearing gloves, etc. It is thought that fatigue is caused by a constant strength. So in the test, a fixed force is applied to evaluate the fatigue of hand.

Grip fatigue test is similar to the ‘grip the brakes of a bike’. The subject was asked to try his/her best to grip two handles together. As soon as the roots of the two handles touch each other, the monitor gives the signal and the action is complete (Fig. 2.2). With reference to O’Hara (1988) and Bishu (1995)’s experience, the subject was required to answer the questions during the test process. During the test, the subject completed one action with the even frequency of 1 time/second. After 20 times, the subject was allowed to rest for 5 seconds and answered questions about fatigue at that moment. Then he/she continued to operate it until he/she could not accomplish the action any more. Pinch fatigue and screwing fatigue have similar test methods to those used for grip fatigue (Fig. 2.3). In all the tests, the subjects were asked to pinch or screw test equipment with springs at a certain speed. As pinch and screwing strength is less compared to grip strength, the number of work times reduces to 10.

ROM

It is easy to measure the hand ROM. A digital camera is used to take pictures of various postures of the hand (Fig. 1.1~Fig. 1.13). The force direction of hand is indicated by the arrow in the figure. In addition, because hand ROM circumrotate the joints, the maximum rotational angle is the only necessary measurement. The ROM of hand and fingers can be acquired through processing the corresponding figures.

Tactile Perception

Strength perception
In order to perceive the existence of strength, the subject was asked to touch the tactometer. As soon as the tactile dot was apperceived, the subject withdrew his hand. The monitor would show the force on the tactile dot (Fig. 2.4).

To perceive the change of force, the subject was required to perceive the different weights of two vessels. In one vessel, the weight is fixed; in the other, the weight varies (Fig. 2.5). The change of strength perception can be detected by weighing the difference between the two vessels by hand. This test is simpler than O'Hara (1988)'s test on perceiving the slide down of objects and it is more universal.

Length perception
Typical "V-test" is applied to test and measure the two-point discrimination of hand. One side of the V-shaped instrument is fixed, the other side is open. The subject moved his/her middle finger slowly into the instrument from the gap to the junction. The subject stopped when he perceived the two side of the instrument (Fig. 2.6).

To test the change of length perception, the subject was given two lengths of which one is fixed length (16*mm*) and the other is alterable length （Fig. 2.7）. The alterable length is the two-pinpoint of vernier caliper. The perceived change of length is the difference between vernier caliper and the fixed length.

Shape identification
Shape identification is that the subject feels the shape of different objects. The objects used in the above test are cubes, spheres and cylinders with the characteristic sizes of 1*mm,* 2*mm* and 3*mm*.

Dexterity

Dexterity among fingers
During the process of work, it is not easy to tell the difference among two fingers and three fingers. So in the test, assembly task is employed to evaluate the two-indexes without considering the differences between the two-indexes (Fig. 2.8). In the test, the subject was informed to put the nut and the hollow cylinder onto a fixed stick in turn. It mainly consists of holding objects by fingers, adjusting positions and putting objects to certain positions.

Screwing nut is a typical test (Fig. 2.9) for testing the dexterity of all fingers. For the purpose of avoiding the problem of different degrees of difficulty of screwing nuts onto the bolt after many times, the test is designed to have the nut completely screwed onto the bolt at the very beginning. However, it has not reached the state that is shown in the right part of Fig. 2.9. In the test, the subject was asked to screw the nut off the bolt, and then to screw it back to the position as shown in the left part in Fig. 2.9.

Dexterity between hand and other parts
During the test process, the fingers of the subject grasped the small stick with a pair of forceps, moved it quickly to above the vessel by turning wrist. The subject then loosed the fingers and put it into the vessel (Fig. 2.10). This test measures the dexterity between hand and wrist.

The most typical test on the cooperation of the two hands is the tying knot task. Like O'Hara (1988)'s and Muralidhar (1999)'s tests, two types of ropes with different degrees of softness are used in this test. The subject was asked to tie a slipknot (Fig. 2.11).

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TEST METHODS

Test subjects

Thirteen young adults (6 females of 23.0 ±5.0 year-old and 7 males of 27.0±4.0 year-old) were recruited among the students of the University. They were all healthy and with good hand strength.

Test equipment

Strength
Dynamometer The minimum graduation of dynamometer is 0.1*kg*; its measuring range is from 0 to 100 *kg*.

Screwing device has a 30-*mm* diameter knurled head (Fig.2.1), its minimum graduation is 0.01*N·m*, and its measuring range is from 0 to 5 *N·m*.

Fatigue
Like Fig.2.2 and Fig.2.3, fatigue devices use springs as a fixed force. According to the different test contents, the springs are different from the devices.

ROM
All the pictures of ROM are shot by digital cameras. (Canon PowerShot A310, 3.2 megapixels)

Tactile perception
The minimum scale of 1*g*, and the measurement category is 1～1000*g* (Fig.2.4).

The variety of the strength perception device consists of two vessels. One is a “standard” vessel with steel balls of certain weight (151*g*). The other is a “changeable” vessel with which could be put different number of balls in it (Fig. 2.5).

The V-shaped tool is composed of two 150*mm* straight edges connected at one end and with a maximum gap of 15*mm* at the other end.

The change of the length perception device includes two parts: standard length and vernier caliper (Fig.2.7). The standard length provides a standard two-pinpoint, where the distance between the two pinpoints is 16*mm*; and the vernier caliper can make the distance about 16*mm* by regulating the vernier.

The object shapes consist of spheres, cylinders and cubes with sizes of 1 *mm*, 2 *mm* and 3 *mm*.

Dexterity
Assembly board There is a 3*mm* diameter iron stick fixed onto the assembly board, with some nuts and tubules beside it (Fig. 2.8).

Nuts and bolt board There are four different-size sets of bolts and nuts. The bolts have diameters of 16*mm*, 12*mm* and 8*mm*, and they are fixed onto the board (Fig. 2.9).

Forceps and small sticks Forceps and small iron sticks (ϕ=1.7*mm*， *L*=30*mm*) (Fig. 2.10).

Knot tying board There are ropes with two different degrees of softness (ϕ=6*mm* and ϕ=3*mm*). For each kind of rope, there are two pieces. Ropes that have the same degree of softness are used in tying knots (Fig. 2.11).

Test methodology

Strength

In the tests, the subject was asked to sit calmly in front of the table and put his/her arm horizontally onto the table. Each time after finishing one type of strength test, the subject was asked to rest for at least 5 minutes and to do the next test after the recovery. Strength tested can easily make the subject tired, and also prevented him/her from reaching his/her maximum strength. So it was necessary after 3 rounds of tests with different poises to rest one day.

Fatigue

The subject was asked to grip the fatigue device with the even speed of 1 time/sec in the test. He/She had a 5 second to rest and answer questions about fatigue after 20 gripped the fatigue device. He/She repeated the above process until the monitor could not give the signal of the fatigue device.

The methods of pinch and screwing fatigue were similar to that of grip fatigue. The only difference was that the operational time was 10.

ROM

The subject was asked to do all types of actions shown in Fig. 1.1~Fig. 1.13, and pictures were shot using a digital camera.

Tactile perception

As tactile perception would be effected by eyes, the test devices must be invisible to the subject. The subject was asked to have his /her eyes covered. The number of the repeated test depended on the test experiences (Ding, 2004).

(1) The subject was asked to touch the object with his/her finger and withdrew the finger as soon as he/she touched the object. The data was displayed on the monitor. He/She repeated the test 3 times.

(2) The balls were put into the “changeable” vessel and these balls had a similar weight to those in the ‘standard’ vessel. Then by used his/her hand, the subject was asked to compare the weight difference between the two vessels and tell the result. He/She repeated the test 10 times.

(3) The subject moved his/her middle finger slowly from the gap to the junction of the V-shaped instrument. He/She stopped as soon as He/She touched both straight edges. He/She repeated the test 3 times.

(4) The position of the main ruler on the vernier caliper was adjusted so that the distance between the 2 pinpoints was about 16*mm*. Then the subject touched the different two-pinpoints with his/her finger and gave the result. He/She repeated the test 10 times.

(5) Spheres, cylinders and cubes, with characteristic lengths of 1 *mm*, 2 *mm* and 3 *mm*, were given to the subject in random order. The subject used his/her fingers to touch the objects and to feel the shapes of the objects and to give the result. He/She repeated the test 10 times.

Dexterity

Because the subject was required to take part in the test in his/her best body condition, the test devices were put in proper positions onto the table to ensure that the subject operated comfortably. In addition, subject was trained before the formal tests.

(1)After received the instruction to start, the subject in turn got the nut and the tubule and put them onto the iron stick. As soon as the subject had got 3 nuts and 3 tubules, the laboratory assistant wrote down the time elapsed. He/She repeated the test 3 times.

(2)After got the order to start, the subject began to unscrew the nut. As soon as it had been done, he /she showed it to laboratory assistant and immediately screwed it on. The laboratory assistant then recorded the time spent in the operation. He/She repeated the test 3 times.

(3) After received the signal to start, the subject grasped the small stick with forceps and put it into a vessel at the side. After 30 second, the subject stopped the operation. The number of small sticks that had been put into the vessel was collected. He/She repeated the test 3 times.

(4) After got the instruction to start, the subject began to tie a knot (Fig. 3.11). After the subject finished tying two knots, the laboratory assistant wrote down the time elapsed. He/She repeated the test 3 times.

DATA ANALYSIS

Strength

Because the strength of each muscle is difficult to test separately, the classification of strength is mainly based on working positions and poises, and the muscles involved in the tests are also stated.

Grip

Fingertip grip is mainly the strength of FDP; the middle of the fingers grip is mainly the resultant force of FDS and FDP; finger root grip is the resultant force of LU, MI, FDS and FDP. So finger strengths are listed here in ascending order: fingertip, the middle of fingers and finger root. And the joints between PIP and MCP are the base point of finger torque, the arm of force in a finger listed here in ascending order are finger root, the middle of the fingers and fingertip. Considering the strength of muscle and the arm of force, the moment of the middle of the fingers should greater than the other two and the test results proved this (Table 2, P<0.001). So it is obvious to test only the middle of the fingers grip when the maximum grip strength is tested.

According to the finger biomechanics, the poise has little influence to the force of the hand. So grips of different poises are about the same and this is proved by the comparison among different postures of grips (P>0.05). So normally, the different poises of the hand can be ignored in work efficiency tests and this is the same conclusion as drew by the O'Hara (1988).

Pinch

The different poises have no significantly influence on strength, as in the prior discussion, so in pinch tests, the different-posture tests were not done.

Through the comparison of pinches (Fig. 3), the pinch strength of thumb, index finger and middle finger has not significant difference from that of the thumb in the IP of the index finger(P>0.05), and the thumb pinch is significantly greater than that of other finger(P<0.01). Index finger pinch has not significantly difference from that of the middle finger (P>0.05). Both of them are significantly greater than ring finger pinch or little finger pinch (P<0.01). In addition, ring finger pinch is significantly greater than little finger (P<0.01). This is the same conclusion as reached by the Swanson (1970) research. Based on this, if thumb pinch is obtained, the maximum pinch can be determined.

Screwing torque

In the tests, there is not significantly difference between the screwing torque with the thumb, the index finger and the middle finger and the screwing torque with the thumb and the index finger (Fig. 4, P>0.05). All fingers screwing torque is very significantly greater than the other two screwing torque (P<0.01). So when the maximal screwing torque needs to be tested, the only thing is to test the screwing torque with all fingers. As our knowledge, there have not data about it.

Others

For the same poise, the strength of the males are significantly greater than that of the females (Table 2, P<0.01).

Actually, few indexes can be applied in the appraisement of strength subjected to testing condition. The results show that the greatest strength of each second stage index can be used to appraise the strength of hand precisely, i.e. the greatest grip is the middle of the fingers, the greatest pinch is the thumb pinch, and the greatest screwing is all finger screwing (There have "●" behind the index of table 2). When only one index can be used in the appraisal of strength, the greatest grip strength is usually used to replace the first stage index as appraisal index (Swansen,1970; Ram,1995; Melissa,2001), since it is the greatest manual strength and the test equipment is very simple (There has "▲" behind the index of table 2). But the greatest pinch and the greatest screwing also can be applied for the special condition.

Fatigue

Grip fatigue

Because the strength of male is relatively bigger than that of the female, it is obvious that the index of this is more than twice that of the female (Fig.5 and Table 2). But to subject with different degree of strength, the same test devices are applied in this test, the difference is great. Very few subjects with greater strength do not feel fatigue during the test and they even feel a kind of recovery at the later stage in the test. So there are certain problems in the testing of fatigue using a fixed force. The test methods for fatigue should be determined according to different research contents. For instance, for EVA spacesuit glove, the appraisal test can apply 40% of the maximum grip for each subject to test grip fatigue. Thus it avoids the problems which the subject with greater strength do not feel fatigue, and those with smaller strength can hardly use the fatigue devices. It was proved in our succedent research and O'Hara has similar research (1988).

Pinch fatigue

Because pinch strength is relatively less than grip strength (maximum pinch: maximum grip = 115:546), subjects quickly feel fatigue (Table 2) in the test. In addition, because there is no great difference between the minimum female pinch and maximum male pinch, (maximum pinch – minimum pinch = 77.7N, maximum grip – minimum grip = 379N), there is no subject that does not feel fatigue all the time, and neither is there any subject who cannot use the pinch fatigue devices because of little strength. Because the difference between subjects with the same gender is not great, 2 pinch fatigue devices are the optimal design for both genders respectively.

Screwing fatigue

When hand sweats, the friction coefficient is smaller and it demands greater strength. Compared to the other two methods on testing fatigue, hand sweating has more influence in this test and this leads to greater difference between subjects (Table 2). As the grip fatigue test, the evaluation of screwing fatigue also should be determined according to different research contents.

ROM

Thumb

Because thumb ROM is like a taper, thumb side extension is added to make it complete to manifest thumb ROM based on the O'Hara (1988). The results of the tests reveal that female thumb ROM is identical to the male on the whole without significantly difference (P>0.05). Comparing with literature (Swansen A.B et al, 1970), thumb MCP1 and PIP1 flexion are identical result.

Other fingers

Comparing other fingers extension and flexion (Table 2), the ROM of the other fingers in the female is not significantly different from the male (P>0.05), except small finger is significantly larger (P<0.05). For the index finger by itself, male two-index are clearly better than female (P<0.05). In other words, the independence of the female index finger is worse than that of the male.

The wrist

Like the ROM of the thumb, the wrist's ROM is also like a taper. Female wrist ROM is about equal to the male, except that radial deviation and wrist extension are obviously better than that of the male (Table 2， P<0.01). Comparing reference (Shingo O, Noriyuki K, 2001) and Laura (2003), all data are identical except that female radial deviation is larger than that of reference.

Tactile perception

Strength perception

Female perception of tiny force has not significantly different from the male perception (Table 2, P>0.05). Apperceiving strength among female subjects is similar, and it is between 1 and 2.5*g*; the perception of male subjects is relatively scattered, and falls between 1 and 5.75*g*.

Standard weight may affect the subjective judgment when holding an object. So in the test, the subject did not know which was the 'standard' one, and he had to judge which one was heavier based on his perception. Tests show that the female has not significantly different from the male when standard weight is 151*g* (Table 2, P>0.05). In addition,

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the change of strength perception may be different when using different standard weight. Further investigation is needed.

Length perception

The classical ‘V-shape’ test is analyzed by the distance between the starting point and the point at which the subject could discriminate two separate edges, but it is difficult to compare the length perception of the different fingers. In actual ‘V-shape’ test, the touch place between finger and the ruler is a touch line. The shorter the touch line is, the more sensitive the finger is. The results show that female touch line is similar to that of the male (Table 2， P>0.05) and the length of the female line is from 2.8 to7.9*mm* and the male line is from 1.3 to 6.6*mm*.

To the tiny change of length, except that few subjects have big difference, most subjects have their errors between 0.5 and 2.0*mm*. Female has not significantly difference from male (Table 2， P>0.05).

Shape perception

In the tests, we deliberately design and provide the subject with objects that are not strict spheres, cylinders and cubes, but those objects are spheres, cylinders and cubes that can be easily distinguished. The tests show that this design effect is excellent especially when cylinders are tested. Subjects need to apperceive the shape of the object precisely before they can judge it correctly.

From the tests, it is clear that mistakes are easily made when the subject apperceives objects of characteristic sizes of 1*mm* and 2*mm*, and the mistake ratio falls significantly when the characteristic size is 3*mm*(P<0.05), and the mistake ratios of females have not significantly difference from that of males (Fig. 6, P>0.05). The mistake ratio of 3*mm* is similar to the mistake ratio of O’Hara’s small object (12.5%). In addition, in the tests, subjects easily make mistakes when they judge spheres or cylinders, but it is not with cubes. Although it corresponds to perception mechanism, it needs to be affirmed by further research.

Others

Because shape identification works by collaboration of different perceptible signs in brain, in which, strength perception and length perception play the important role, if only one index can be used in appraisal, shape perception is a better index and then another index can be chosen.

Dexterity

Assembly Test

In the assembly, the work is mainly the collaboration of the thumb, index finger and middle finger to take up the nut or the small pipe, adjust it to an appropriate position, and then put it onto the iron stick. The test mainly tests the accordance of the above three fingers while doing the work. Tests show that the fingers of female subjects have not significantly difference from those of the male (P>0.05).

Screwing nut

Screwing nut mainly tests finger dexterity when screwing objects with fingers. Normally, it demands all the fingers to move quickly and do the screwing. In the test, male subjects spend a bit less time on screwing the nut than the female subjects. But it has not significantly difference (Table 2, P>0.05). Simultaneously, as O’Hara’s research, there have not significantly difference among the time of assembly different nut (Table 2, P>0.05).

Clamping small stick

Clamping small stick is accomplished by the harmonious operation of the fingers and the wrist. As females are normally more dexterous than males in everyday life, females are 14% more quickly than males in clamping the stick (Table 2, P<0.01).

Tying Knot

The purpose of knotting is to test the harmonious operation between the two hands. It is the colligation of above three indexes. This index result shows that females are 16% more quickly than males (Table 2， P<0.01). The male average knot tying time is similar to O’Hara’s result (5.85±2.02*sec*).

Others

Besides the above conditions, the following can be found on the harmonious operation of hands:

(1) In the dexterity tests, the thumb, index finger and middle finger are involved to some extent, and the harmonious operations of the above 3 fingers directly affect the test results. So the harmonious operations of the 3 fingers should be included in a manual work dexterity appraisal.

(2) In the work, there is a kind of tactics in the harmonious operation between fingers. This is closely related to the physiological features, the skillfulness, training, etc.




Fig. 1.1 MCP1 extension PIP1 extension

Fig. 1.2 MCP1 flexion PIP1 flexion

Fig. 1.3 Thumb side extension

Fig.1.4 MCP flexion PIP flexion




Fig.1.5 MCP extension PIP extension

Fig.1.6 PIP3 flexion

Fig.1.7 PIP5 flexion

Fig.1.8 PIP2 flexion




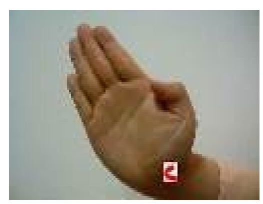

Fig.1.9 Maximum angle between index and middle finger

Fig.1.10 Wrist flexion

Fig.1.11 Wrist extension

Fig.1.12 Radial deviation




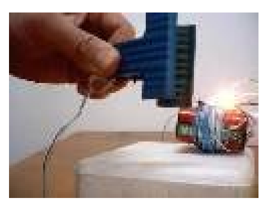

Fig.1.13 Ulnar deviation

Fig. 2.1 Screwing

Fig. 2.2 Grip fatigue

Fig. 2.3 Pinch fatigue




Fig.2.4 Perceiving the existence of force

Fig.2.5 Perceiving the change of force

Fig. 2.6 “V-test”

Fig. 2.7 The change of length perception

Fig.2.8 Assembly Test

Fig. 2.9 Screwing nut test

Fig. 2.10 Clamping small stick

Fig. 2.11 Knot tying test

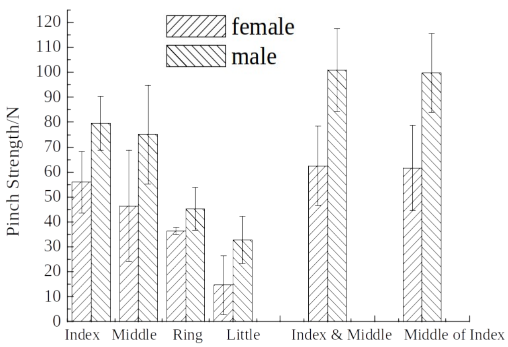

Fig.3 The strength of finger pinch

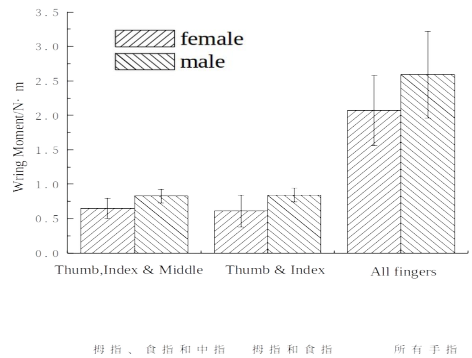

Fig.4 The screwing torque of finger

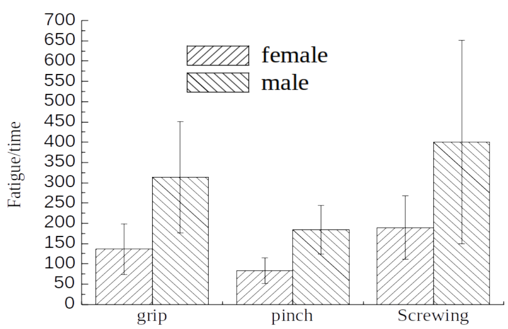

Fig.5 Fatigue comparison

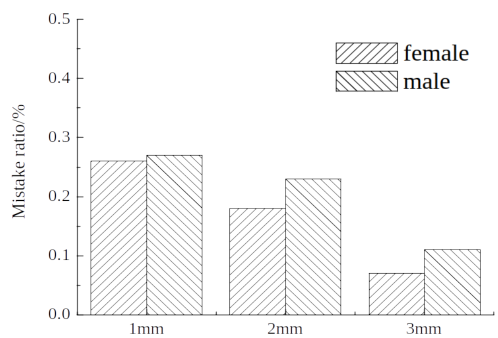

Fig.6 Shape perception

Fig.7.1 Red gloves(high temperature resistant)

Fig.7.2 Red gloves(high temperature resistant)

Fig.8 Welding torch

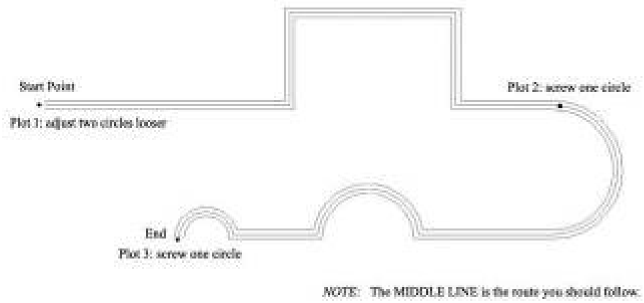

Fig.9 Given route (with request)

Table 1 The test appraisal system of manual performance efficiency

Level	The first stage index	The second stage index	The third stage index
1	Strength	Grip	Fingertip grip
			√The middle of fingers grip
			Finger root grip
		Pinch	Thumb and index finger pinch
			Thumb and middle finger pinch
			Thumb and ring finger pinch
			Thumb and little finger pinch
			Thumb, index finger and middle finger pinch
			Thumb in the middle of index finger pinch
		Screwing	Thumb, index finger and middle finger screwing
			Thumb and index finger screwing
			All fingers screwing
	Fatigue	Grip fatigue	√
		Pinch fatigue	
		Screwing fatigue	
	ROM	Thumb	√MCP1 extension
			√MCP1 flexion
			√Thumb side extension
			√PIP1 extension
			√PIP1 flexion
		Other fingers	√MCP extension
			√MCP flexion
			√PIP2 extension
			√PIP2 flexion
			PIP3 flexion
			PIP5 flexion
			√PIP2 flexion
			√Maximum angle between index and middle finger
		Wrist	√Wrist flexion
			√Wrist extension
			√Ulnar deviation
			√Radial deviation
	Tactile Perception	Strength perception	√Apperceiving strength
			√Change of strength perception
		Length perception	Two-point discrimination
			√Change of length perception

		Shape perception	√
2	Dexterity	Dexterity among fingers	Dexterity between thumb and index finger
			√Dexterity among thumb, index finger and middle finger
			√Dexterity of all fingers
		Dexterity between fingers and other parts	√Dexterity between wrist and fingers
			√Dexterity between two hands
3	Integrated hand performance	Real-world work	

Note: strength indexes consists of three postures: suppination, pronation and level.

Table2 Statistical comparison of the evaluation of manual performance and optimal index($\bar{x} \pm s$)

Work efficiency index					Test result	
Level	The first stage index	The second stage index	The third stage index		Female	Male
1	Strength	Grip ▲/*N*	Suppination	Fingertip grip	143.4±46.0	228.2±46.0
			Pronation		164.4±46.4	216.1±54.9
			Level-palm		149.1±39.5	219.4±53.3
			Suppination	The middle of finger grip●	250.8±40.2	403.9±77.2
			Pronation		244.6±44.1	392.9±79.8
			Level-palm		257.2±52.0	411.2±88.1
			Suppination	Finger root grip	200.9±47.3	338.4±83.6
			Pronation		173.8±46.5	301.6±80.8
			Level-palm		176.5±51.5	320.9±89.5
		Pinch/*N*	Thumb and index finger pinch		56±12.3	79.6±10.8
			Thumb and middle finger pinch		46.5±22.4	75.1±19.8
			Thumb and ring finger pinch		36.3±1.35	45.2±8.5
			Thumb and little finger pinch		14.7±11.8	32.8±9.5
			Thumb, index finger and middle finger pinch		62.5±15.9	101±16.6
			Thumb in the middle of index finger pinch●		61.7±17.1	99.7±15.8
		screwing/*N·m*	The screwing torque on thumb, index finger and middle finger		0.65±0.15	0.83±0.10
			The screwing torque on thumb and index finger		0.61±0.23	0.84±0.1
			The screwing torque on all fingers●		2.07±0.51	2.59±0.63
	Fatigue	Grip fatigue●▲/time			136±63	314±137
		Pinch fatigue●/time			83±31	184±60
		Screwing fatigue●/time			189±78	400±251
	ROM	Thumb	MCP1 extension●/degree		29.9±10.6	37.7±19.9
			MCP1 flexion●/ degree		15.1±5.8	10.9±9.8
			MCP1 side extension●/ degree		59±6.2	60.4±9.6
			PIP1 extension●/ degree		68.6±15.7	74.1±13.6
			PIP1 flexion●/ degree		29.4±10.8	30.9±10.0
		Other fingers	MCP extension●/ degree		79.1±7.2	81.2±6.7
			MCP flexion●/ degree		105.5±7.3	100.0±16.9
			PIP extension●/ degree		24.9±6.5	23.5±13.8
			PIP flexion●/ degree		10.5±5.2	7.5±5.5
			PIP3 flexion/ degree		108.2±7.2	104.2±8.7
			PIP5 flexion/ degree		98.5±10.0	88.3±13.4
			PIP2 flexion●/ degree		97.5±6.6	98.6±8.2
			Maximum angle between index and middle finger●/ degree		41.2±15.0	47.3±15.7
		Wrist	Wrist flexion●/ degree		70.8±12.1	64.8±10.6
			Wrist extension●/ degree		71.5±10.7	60.8±12.7

			Radial deviation●/ degree		35.6±18.7	15.7±8.1
			Ulnar deviation●/ degree		51.8±7.6	58.4±11.7
	Tactile Perception	Strength perception	Apperceiving strength●/*g*		1.47±0.53	2.01±1.38
			Change of strength perception●/*g*		6.8±3.6	8.4±3.7
		Length perception	Change of length perception●/*mm*		4.9±1.7	3.8±1.4
			Two-point discrimination●/ *mm*		0.99±0.8	1.24±0.58
		Shape perception▲	1*mm*object mistake ratio●/%		0.26	0.27
			2*mm* object mistake ratio●/%		0.18	0.23
			3*mm* object mistake ratio●/%		0.07	0.11
2	Dexterity	Dexterity among fingers	Dexterity among thumb, index finger and middle finger（assembling/*s*）		8.8±1.3	8.9±1.3
			Dexterity among all fingers●（screwing nuts /*s*）	16*mm*	10.5±3.7	9.0±1.8
				12*mm*	9.8±1.8	10.5±1.4
				8*mm*	8.9±0.9	9.8±2.6
		Dexterity between hand and other parts▲	Dexterity between wrist and fingers●（Clamping small sticks/piece）		37.0±4.5	31.7±4.7
			Dexterity between the two hands●（tying knots/*s*）	Rope size(3*mm*)	5.0±0.9	5.9±1.0
				Rope size(6*mm*)	4.8±0.9	5.6±1.0
3	Integration of manual work	Actual work				

Table3 Results of the verification experiment ($\overline{x} \pm s$)

Index			Different conditions		Without gloves	Red gloves	Green gloves
Efficiency appraisal index	Strength		The middle of finger grip /kg		37.18±8.6	24.534.19**	23.52±5.35**
			Grip fatigue /time		26.67± 10.7	24.17 ±11.41	26.67±9.74
	ROM	Thumb	MCP1 extension/degree		79.29±5.36	66.07±11.18**	64.89±7.47**
			MCP1 flexion/degree		61.5±15.98	58.16±12.98	54.18±10.73**
			MCP1 side extension/degree		19.99±8.5	16±9.35*	14.61±8.19**
			PIP1 extension/degree		66.35±11.66	57.11±12.80*#	48.05±9.27**#
			PIP1 flexion/degree		45.19±7.51	36.72±8.99**	30.08±8.91**
		Other fingers	MCP extension/degree		106.8±3.5	133.4±3.7**	136.5±2.9**
			MCP flexion/degree		22.25±3.27	20.12±5.36	20.85±4.97
			PIP extension/degree		151.3±4.3	148.7±8	150.2±4.5
			PIP flexion/degree		84.7±10.4	85.8±11.7#	93.9±10.4#
			PIP2 flexion/degree		54.5±11.6	58.3±5	49.2±12
		Wrist	Wrist flexion /degree		112.7±8.3	107.6±3.8*	110.1±3.8
			Wrist extension/ degree		117.5±8.7	117.5±8.7	121.5±7.6
			Radial deviation/ degree		146.9±13	141.2±10.9	150±15.7
			Ulnar deviation/ degree		120.8±15.3	120±12.9	121.9±11.7
	Tactile Perception		Apperceiving strength /g		0.3±0.12	16.92±12.5*	19.37±9.26*
			Change of strength perception -10g /%		0.07±0.09	0.18±0.17	0.23±0.11*
			Two-point discrimination /%	1mm	0.12±0.08	0.14±0.07##	0.32±0.14**##
				2mm	0±0	0.05±0.05	0.19±0.16
				3mm	0±0	0±0	0.09±0.17
			Shape perception /%	3mm	0±0	0.02±0.04	0.45±0.21**
				4mm	0±0	0.22±0.11**	0.23±0.11*

	5mm	0±0	0.17±0.17*	0.22±0.13
Dexterity	Dexterity among thumb, index finger and middle finger（assembling/*s*）/s	20±3.85	54.78±15.86**	68.06±14.12**
	Dexterity among all fingers（screwing nuts /*s*）	27±3.4	29±3.87	27±3.02
	Dexterity between the two hands（tying knots/*s*）	6.39±1.58	14.17±4.12**	16.06±5**
Actual work(gas welding)simulation test /*s*		50.78±7.17	54±8.63*	54.78±5.53*

Note： * significant different from without gloves， # significant different between two gloves（p＜0.05）； **，##stand more significant different（p＜0.01）

CONCLUSIONS

The result presented here shows that when work efficiency is appraised, the best appraisal indexes and appraisal methods to different work can be designed based on the appraisal system as shown in Table 2, in which “●” represents the best appraisal index in appraising manual work accurately (Note that to strength, one of supination, pronation and level posture is enough), and “▲” indicates that the optimal appraisal index can be used to replace the first stage index as appraisal index when only one appraisal index can be applied in the first stage index.

Strength

As the hand muscles, there are many hand strength indexes. However, it is impossible and unnecessary to measure all of the indexes in actual work. From the research on hand strength, the following conclusion can be obtained:

(1) The influence from different poises can be neglected during the strength appraisal.

(2) The maximum grip is generated from the middle of the fingers; the maximum pinch is from the thumb and the maximum screwing torque is the one when all fingers are working together at the same time. So it only needs to obtain the above three while measuring the maximum strength.

(3) The greatest grip strength can be applied to replace the first stage index as appraisal index, when only one index can be used in the appraisal of strength.

Fatigue

The appraisal of fatigue is relatively complex compared to other indexes in the first level. The tests show that the different strengths should be designed for different subjects and the same amount of strength cannot be used to test all subjects in grip and screwing fatigue tests.

ROM

ROM is the maximum circumvolving ranges that different parts of hand can reach, so it is impossible to use only one index to replace all the other indexes. All indexes should be used in the appraisal. However, according to different work contents, some indexes with little influence can be neglected.

Tactile perception

As different sensors are used to accomplish different tactile perception, the best way is to appraise all perception indexes. But if only one index can be used in the tactile appraisal, shape perception is better than other two indexes.

Dexterity

Dexterity is an integrated index of collaboration of the different parts of hand. In manual work, the thumb, index finger, middle finger and wrist are the majority that participates in work. So the dexterity of these parts must be appraised whilst appraising the dexterity of hand. In work, dexterity is closely related to the tactic, physiology, the skillfulness and training, etc.

VERIFICATION EXPERIMENT ON EFFICIENCY APPRAISAL SYSTEM OF THE MANUAL WORK

In order to verify the efficiency appraisal system of the manual work established above, an efficiency appraisal test on heat resistant gloves was designed. The results was then compared with the actual work simulation, and consequently come to a validation conclusion.

Test design

Many manual work need people to wear gloves, and gloves must have effects on our efficiency. Heat resistant gloves, one of the labor insurance gloves, are used in quite many conditions like gas welding, pudding, steel welding, etc.

Two kinds of heat resistant gloves (Fig.7.1-7.2, named as red gloves and green gloves respectively) which are different in material and exterior were chosen to be tested for efficiency appraisal; while an actual work(gas welding was chosen considering the limits) simulation test is designed to give a comparison of two kinds of gloves. At last, results of two parts of the test are analyzed, then come to a conclusion.

Two parts of the test are designed in detail as followed.

Efficiency appraisal test
The index chosen here are those marked with"√"in Table 1. According to the special situation of the manual work with gloves, change of strength perception and shape perception was analyzed by error rate, and two-point discrimination was canceled.

Appraise each index while testing both without gloves and with the two kinds of gloves respectively.

Actual work simulation test
This part of test is a simulation of an actual work (gas welding) of heat resistant gloves, and based on it, the two different gloves were compared with each other for quality.

In the test, subjects should move the welding torch (Fig.8) along the given route (Fig. 9), during which knobs on the welding torch would be adjusted. Index to be analyzed is the efficiency of the work, which is the time it takes.

Test method

Ten young men (20.0 ±1.0 year-old) were recruited among the students of the University. They were all healthy and with good hand strength.

Efficiency appraisal test
Appraise the index in Table 1 marked"√", and method is as mentioned above.

Actual work simulation test
Welding torch was fixed with a pencil at the end of it, and subjects hold the handle of the welding torch, move it so that the pencil can draw line along the given route (see Fig.9), during which subjects should adjust two knobs of the welding torch at the certain plots marked in Fig. 9 according to given requests (See Fig. 9).

The time subjects spent and the times of the error were recorded. The test was repeated 3 times.

Error was defined as overstepping the routes' two lines during the test.

Test results and analysis

Table 3 shows the results of the test. Here followed an overall analysis instead of analyzing each index.

In a whole, as to the efficiency appraisal test, all the indexes show no significant difference except fatigue, for the red gloves are better than the green ones. And for the actual work simulation test, the red gloves are better too, but without significant difference.

Analysis: the red gloves are thinner and softer in material compared with the green ones, so it becomes better than the other in index of strength, ROM， tactile perception and dexterity. While as to the fatigue, the results are different, because the device makes hand uncomfortable, and the green gloves are relatively thicker so that it can provide a physical protection. The actual work simulation test has little to do with fatigue, but is related to the index of ROM, tactile perception and dexterity, in which the red gloves show some advantages. Results of the two parts of test both tally with the quality of the two kinds of gloves.

Conclusions

According to the results, the efficiency appraisal test of two heat resistant gloves using the optimal system shows the same results with the actual work simulation test. Therefore, the practicality of the efficiency appraisal system of the manual work established was verified.

By testing the efficiency appraisal system of the manual work, it is established that the optimal efficiency appraisal system of the manual work and the optimal efficiency appraisal index under some restriction. They can not only offer the theoretical foundation for the design of gloves, manipulator and some other appliances, but also, through the results of the verification experiment of two heat resistant gloves, it is proved thatthe relevant results can be utilized in the manual work plan and efficiency appraise, and so on.

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