Study on the Appraisal Methods of Hand Fatigue*

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Abstract. Objective: The evaluation methods of hand fatigue are built and the aim is to provide reference for the numerical human fatigue appraisal. Method 12 females and 14 males in two groups participated in the experiments of changeless force fatigue, which included the grip and pinch and screw, and took part in the nondimensional force fatigue. Result ①Hand fatigue could be full evaluated basing on grip and pinch and screw. ②Using stable force could test the fatigue of manual work simply, but it would be largely affected by the characteristic of sex. ③The nondimensional evaluation can avoid the impact results from the different forces of testees. Conclusion Hand fatigue could be full evaluated basing on grip and pinch and screw. The nondimensional evaluation is a feasible method to research numerical human manual fatigue.

Keywords: Hand performance, Fatigue, Evaluation, Nondimensiona.

1 Introduction

Falling under the influence of many factors such as figure, structure, pressure of spacesuit glove system and the low temperature environment, the cosmonaut's manual work are easily to be tired, which could lead to the biggish impact on space work[1]. But it is need to make much experimental evaluation for any modification of the lifesaving equipment system [1]. Experiments would be largely reduced if numerical human evaluation could be used in advance [1]. But fatigue is a complex physiological phenomenon to describe difficultly in building numerical human model. In especial, hand is mainly tools and it needs to simplify muscle, ligament and other tissues model in manual fatigue evaluation. A logical evaluation method is asked for to compare the consistency between human and the numerical human.

Generally, manual fatigue can be evaluated from three aspects as follows: physiological fatigue, subjective fatigue and action decline [2~9]. By all appearances, physiological fatigue and subjective fatigue can not applied to the numerical human, and only action decline can. Though there have many studies on the action decline

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[2~9], but those often base on the academic study [2],[7],[8], and these studies still can not satisfy the demand generated from manufacture and evaluation of spacesuit glove system. Such demand is "few but extractive" [2], [3]. Therefore, this paper tries to develop the bare hands' evaluative research of dividing the fatigue into changeless force fatigue and nondimensional force fatigue according to the theory that force can be divided into changeless force and nondimensional force. The purpose of this research is providing the feasible appraisal methods for performance fatigue of spacesuit human – glove system.

2 The Efficacy Analysis of Fatigue

2.1 Mechanism for the Occurrence of Work Fatigue

Physical fatigue is the especial representation after actions lasted for some time such as weariness and lack of force. When the physical fatigue is severe, the muscle aches. The main reason of this phenomenon is the decline of Adenosine Triphosphate (ATP), which could generate energy for human. In addition, during works, the accumulation of lactic acid results from the lack of oxygen can make the tired feeling intensive.

2.2 Fatigue Analysis of Manual Work

According to the mechanism of manual action and space work of cosmonauts, the main function of manual space work can be defined as grab, hold, grasp, turn and twist. According to the definition of force [3], this function can be simplified. It is three kinds of force: grip, pinch and screw. Therefore, the evaluation of fatigue of manual space work also includes fatigue of grip pinch and screw. The fatigue of grip is the tired instance of all fingers except for the thumb. The main measure work is testing the tired situation of muscle of fingers and palm. Some muscles of fingers are involved in the pinch measure. Because of that these muscles' force is definitely larger than the thumb [3], the pinch fatigue is testing the fatigue extent of some curving muscles that are connected with thumb. Screw is a combination of two actions, which are pressing and screwing. The muscles for griping and pinching and some muscles of hands generate the action called screwing. The measure for screw is a synthetical test of hand muscle's fatigue.

3 The Design of Experiment

The fatigue discussion of Nina、Shingo、Tommy and Edwatds is mainly about the physiological process of intramuscular fatigue [3~7]. Moreover, some experiments of cosmonaut's fatigue done by O'Hara and Serge are not comprehensive [2], [8]. It is inevitable that in order to program the cosmonaut's space work, it is necessary for us to realize the fatigue that can influence the accuracy of work. The fatigue not only includes fatigue of grip but also involves pinch and screw. Therefore, this text firstly studied the fatigue of these three kinds of stable force, and then tested the fatigue of

nondimensional forces. In order to study completely, the research added in the body's subjective feedback to help fatigue appraisal.

3.1 The Fatigue of Stable Forces

When the cosmonaut is doing the space work, he must use such actions as grasp or grip[2], [6], [7], which will be influenced by the counterforce generated by resistance of gloves and inside stress of clothes. Same kinds of gloves could generate the uniformly stable stress, which will not change by different people. According to this, a stable force can be used to evaluate the fatigue of hands. The test of fatigue of grip was the same as "griping the bicycle's handles" (Fig. 1.1). The testee griped the two handles together, when the roots of handles were tangent, the indicator light on the display lighted, then one action finished. The testee must finish this action with the frequency of 1 time per second on average. After 20 times and a five minutes rest, the testee would be asked some interrelated questions in table 1 [2], [5].

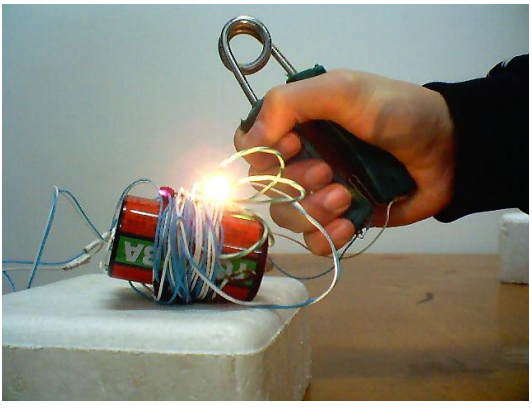

Fig. 1.1 Grip Fatigue

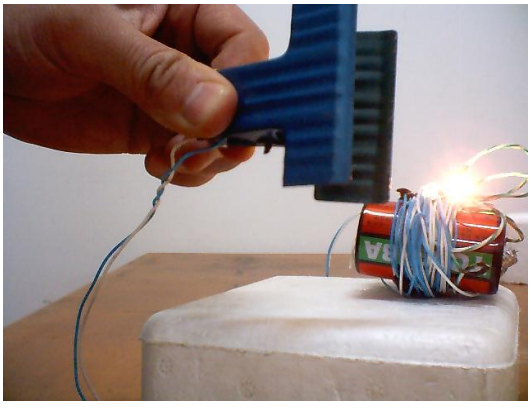

Fig. 1.2. Pinch Fatigue

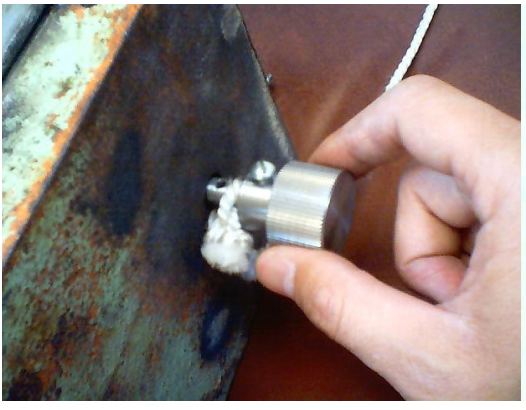

Fig. 1.3. Screw Fatigue

Table 1. The Fatigue Scale

Fatigue level	Fatigue scale
1	Feel the same as the beginning, no noticeable fatigue
2	Light fatigue — between1&3
3	Feel some resistance to squeezing the handle, moderate fatigue
4	Fatigue – between 3-5
5	Unable to effectively squeeze the handle, complete fatigue
6	Stop

After judging the fatigue extent of the testee, one circulation was end. The content of next circulation was the same as the first one (Fig. 1.2, 1.3). The test would not stop until the testee could not let the indicator light.

Tests of fatigue of pinch and screw were the same as grip. Because the forces of pinch of screw were little [9], the test time reduced to 10 times.

3.2 Nondimensional Fatigue

Because the differences among testees are remarkable, using the evaluation of stable force maybe can not let the testee with strong strength feel tired. Also, it maybe can not let the testee with small strength reach the real situation of fatigue. In order to deal with this question, the fatigue experiment of NASA used the nondimensional evaluation. However, when using this method in the test, we found that the percentage of the Maximal voluntary contraction (MVC) and the results of the test were questionable. Therefore, this text afresh designed the method of nondimensional evaluation through comparing experiments of grip fatigue. The experiment of fatigue included several circulations, which involved two states, static state and dynamic state (Fig.2). In the static state, testees were asked to keep 20% of their MVC for 10 seconds, while in the dynamic state, testees used the frequency of 15 times per minute to grasp and undo the hand dynamometer. Every numerical value of force must exceed 50% of the testee's MVC. Moreover, testees were asked to repeat the experiment all long until they could not do it any more.

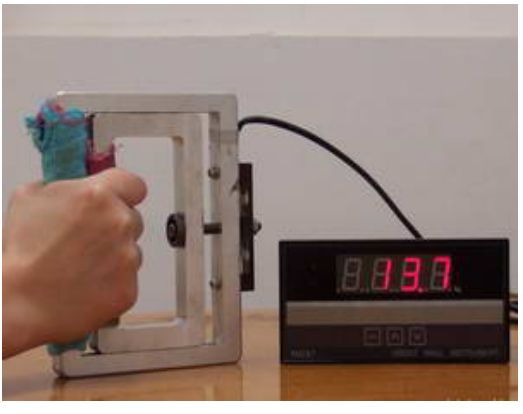

Fig. 2. Nondimensional Grip Fatigue

4 Method of Experiment

4.1 Personnel of Experiment

The experiment went along for two times. Every test involved 13 healthy voluntary students. (6 were female and 7 were male), all of them were right-handed. The first test (age: 25.5±4.1) measured the fatigue of stable force and nondimensional fatigue. The second test (age: 22.3±1.8) validated and standardized the data from the first one. The testees of every experiment were different.

4.2 The Equipment of Experiment

Fatigue device for stable force: the facility used for measuring fatigue adopts the spring for stable force (Fig. 1). According to the different contents of test, the testing forces are also different.

Fatigue device for nondimensional: The grip handle is connected with the display through cable so that it becomes easy to gather the data under the circumstance of experimental cabin (Fig. 2).

4.3 The Mode of Experiment

4.3.1 Fatigue of Stable Force

The testees were seated in front of table, griped the test device with the average frequency of 1 time per second. After 20 times, they could take a break of 5 seconds and answered some relevant questions of fatigue. Meanwhile, the tester measured off the fatigue grade according to the reactive extent of testees (Table 1). The test would not stop unless the testee could not let the indicator light.

Tests of fatigue of pinch and screw were the same as grip, the only difference was that the test time reduced to 10 times.

4.3.2 The Nondimensional Fatigue

The testee was seated in front of the table and griped the test device like figure 2, griping and undoing the device with the frequency of 15 times per second for 1 minute. Every numerical value of force must exceed 50% of the MVC. Then the testee was requested to hold 20% of his or her highest force for 10 seconds, meanwhile, the tester compartmentalized the grade (Table 1) of fatigue according to the reactive extent. The test would not stop unless they could not go on.

5 Result and Analysis

The experiment went on for two times. The first one was used to exploit methods and find out the basic conclusion, while the second one was used to validate and standardize the conclusion. Therefore, the data used in this text is from the second test.

Because of that the difference of force between male and female is comparatively great (male: female ≈ 8:5) [9], the relevant fatigue values of male is twice as high as female or higher (Table 2, $P<0.001$). Therefore, characteristic of sex must be considered in appraisal numerical human fatigue.

5.1 Fatigue of Grip

Compared with O'Hara's method for measuring fatigue, the stable force fatigue adopted the alternation between work and break for 5 seconds, which is an effective and simple method for testing fatigue. When testees finished the experiment, their work efficiency would decline extremely ($P<0.05$), and they needed a long time to restore the fatigue ($t>1$ day). Meanwhile, the experiment adopted the work which includes breaks and was likely to attain the fatigue that accords with the various traits of space work. We also used the work without break to do the experiment, the result indicated that some testees did not really reach the fatigue and they restored immediately. Their work efficiency was not be influenced severely ($P>0.05$). However, when there were large differences among testees' force, some testees with

Table 2. Statistical Data of Hand Fatigue (X±SD)

Efficiency index	Result	
	Female	Male
Grip fatigue/time	136±63	314±137
Pinch fatigue/time	83±31	184±60
Screw fatigue/time	189±78	400±251
Nondimensional grip fatigue /bout	4.0±0.14	9.14±1.7

large force did not feel tired or other testees' with less force could not really reach the fatigue situation. Therefore, this method was only suitable for testees with little differences of force, which had been fully proved in the second experiment. For the testees with large differences of force, we could divide the stable force into several grades and manage the experiment. But it would be hard to evaluate numerical human fatigue.

5.2 Fatigue of Pinch

Because the force of finger was small compared with grip (max grip : max pinch ≈ 4.1) [9], testees would feel tired easily in the test. At the same time, there was not a large difference of pinch among testees (max pinch – min pinch = 78N, max grip – min grip = 379N) [9]. Therefore, this kind of test did not include the phenomenon that strong testees could not feel tired and testees with small force could not pinch the device (Table 2). Two experiments indicated that after the test of pinch fatigue, the testees' work efficiency is influenced largely ($P<0.05$). Thereby, because this method does not have many limitations, the best method for testing pinch fatigue is designing two different devices of testing pinch fatigue for both males and females.

5.3 Fatigue of Screw

The coefficient of friction will decline after the hands perspire, and then the required force will increase. Therefore, compared with other two methods of test, this one could easily be influenced by the sudation of hands, which leads to differences among testees (Table 2, Fig. 3). Like the test of grip, this method is only appropriate to testees without many force differences.

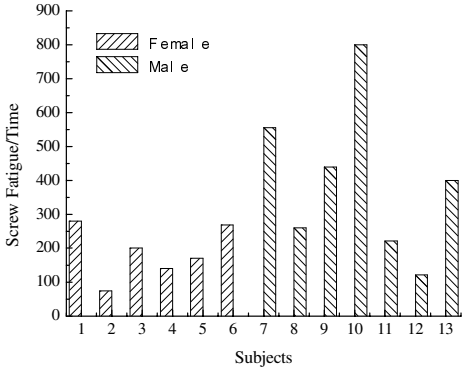

Fig. 3. The Compare of Screw Fatigue

5.4 Nondimensional Fatigue

In order to avoid the large differences of force among testees, this text designed the nondimensional evaluation of fatigue for grip. Experiment indicated that using nondimensional evaluation can effectively avoid the problem that strong testees and ones with small force can not really reach the state of fatigue. So it would be possible to enlarge the realm of selective testees (Table 2). Due to the influence from physiology and mentality, the testees' MVC must be tested many times in order to avoid the fact that the testees' real MVC can not be gained, which may lead to the distortion of the testees' result. Comparing the fatigue of stable force with the nondimensional force, it was found that the nondimensional could evaluate the condition of testees' bodies. The fact was that testees with good condition of body could remarkably complete many circulative times of fatigue test ($P<0.01$). Therefore, nondimensional method of evaluation could be used widely and it is a feasible method to research numerical human manual fatigue.

6 Conclusion

Fatigue is a special representation of muscular force's continuity. Because of differences of tired standard and dissimilar individuals, the experimental result will be influenced to some extent. Through the experimental study of hand's fatigue, we can draw the conclusions as bellows:

1. Fatigue of grip, pinch and screw could completely evaluate the fatigue of manual work.
2. Using stable force could test the fatigue of manual work simply, but there have some difficult in evaluating numerical human fatigue.
3. The nondimensional evaluation can avoid the impact results from the different forces of testees and evaluate the resilience of testees' muscle. It is a feasible method to research numerical human manual fatigue.

Some contents of these four conclusions are already applied in the experiment of wearing simulative spacesuit glove. The effect is remarkable[9].

References

1. Ding, L., Yang, F., Yang, C., et al.: Ergonomics Implications of Extravehicular Activity Spacesuit Glove. J. of Beijing University of Aeronautics and Astronautics 31, 416–420 (2005)
2. O'Hara., Brigann, J.M., Cleland, M., et al.: Extravehicular Activities Limitations Study Volume II Establishment of Physiological and Performance Criteria for EVA Goves-final Report. AS-EVALS-FR-8701. NASA: NAS-9-17702
3. Nina, K.V.: Measurement of Human Muscle Fatigue. Journal of Neuroscience Methods 74, 219–227 (1997)
4. Kim, S.: An Evaluation of Fatigue and Performance Changes During Intermittent Overhead Work, Virginia Polytechnic Institute and State University Master Thesis(2003)
5. Shingo, O., Noriyuki, K.: Neuromuscular fatigue during maximal concurrent hand grip and elbow flexion or extension. Journal of Electromyography and Kinesiology 11, 281–289 (2001)
6. Tommy, O.: Muscle fatigue and calibration of EMG measurements. J. Electromyography Kinesiology 5, 239–243 (1995)
7. Serge, H.R., John, M.: O'Hara: Evaluation of forearm fatigue during EVA pressure glove work. Work 8, 157–169 (1997)
8. Li, D., Longzhu, H., Cchunxin, Y.: An experimental study of effects of active-heating-system for extravehicular spacesuit gloves on working performance. Space Medicine & Medical Engineering 18, 47–51 (2005)
9. Chen, S., Ding, L., Yang, F., et al.: Study on Index optimization of Human mechanics based on basic ergonomic evaluation of spacesuit gloves. Space Medicine & Medical Engineering 19, 106–110 (2006)