Typical Muscle Endurance Force Analysis of Upper Limb Pre and Post the Bed Test Using Detrended Fluctuation Analysis

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Abstract. In order to evaluate the state change of the muscle force of the upper limb for the astronaut after a long time space flight, a bed test is designed to analyze the human performance of this ergonomics problem. The Detrended Fluctuation Analysis (DFA) technique is utilized to evaluate the change situation of the muscle force data. First, some typical force measurement devices are developed and utilized to collect the typical motion force data of the upper limb. Second, a bed test is implemented to get the data of different muscle states: 1) we select 8 subjects to lie on the bed for 45 days; 2) we measure some typical operation force data, such as push and pull, etc, before and after the 45-days bed rest by the typical force measurement devices above. Third, we select the endurance force of some typical motions as samples and employ the DFA method to analyze the fluctuation of them. Finally, we use the results of DFA to estimate the health state of the subjects. Experiment results show us that the typical endurance forces of the subjects pro and post the bed test have a dramatic discrepancy. So this result can be utilized to analyze the health state and build the evaluation method for the astronaut who works in the space station for long time journey.

Introduction

With the development of the astronautics techniques, more and more human activities will be enrolled in the process of space task, such as some scientific experiments or the space maintenance missions. Different to the situation on the ground, even a simple action in the space will be difficult because of the effect of different gravity environment. Working in the zero gravity environments will change not only the physical state of the space craft and its devices, but also the physiological state of the astronauts. Many medical experiments [1] have shown us that the muscles of the astronaut will atrophy if he or she works in the zero gravity environments after a certain period of time. Once the muscle atrophy happens, it is a signal for the astronauts and the physician on the ground to watch out the outbreak of the spacial diseases. So it is very necessary to research and build a method to investigate the health state of the astronaut.

In this paper we introduce a force measurement method and corresponding analysis technique to evaluate the health state of the astronauts. Although many medical diagnosis methods can be use to survey the health state of the astronaut, however the size and the endurance time of the muscle force [2] can reflect the health state of a person directly. One of merits of the force analysis method consists that the muscle force can show us the integrated health state of people [3] such as the physiological health and the psychological health. Another virtue is that the muscle forces are very easy to measure. Since the measurement process of muscle force does not need the astronaut to wear any other additional apparatus on his or her body, this method can bring a lot of conveniences for the astronauts when they work in a narrow environment of a space craft.

In our research work, a bed test is designed to analyze the change situation of the muscle force of some selected subjects. First, some typical muscle force measure devices are designed and employed to collect the motion force data of subjects. The typical operation actions, such as push, pull, lift and twist in different directions can be measured by the sensor fixed in these devices. Second, a bed test is

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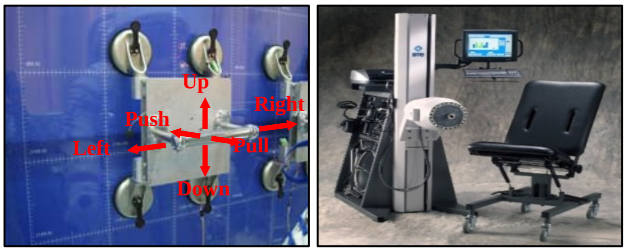
implemented to collect the muscle force data. The bed test needs the subjects to lie on the bed for 45 days. They are not allowed to stand on their foot even in the process of urination. 8 male subjects are selected to finish this experiment. To get evaluation results of the health state, we measure the muscle force of the subjects before and after the bed test by the muscle force measurement devices above. Third we use the Detrended Fluctuation Analysis (DFA) technique [4] to evaluate the muscle endurance force data because we believe the difference of these data is distinct enough to denote the health state of the astronauts.

Experiment Design

The aim of the bed test is to evaluate the difference of the muscle force before and after the 45-days bed rest of the 8 male subjects. All the subjects are healthy and right handed. They are from 25 to 35 years old. Their heights are from 165cm to 175cm. Their weights are from 60kg to 75kg. To achieve that target first some experiment devices are developed and utilized to finish the force measurement task. Then an ergonomics experiment of bed test is designed.

Experiment Devices. Fig. 1 shows us the experiment devices used in this experiment. In some situations when the large mechanics measurement device cannot be used because of the narrow space problem in the space station, we need a portable version of them. (a) shows us the force measurement devices which is designed by ourselves. In (a) we can see that some mechanics sensors are fixed in different positions of a force measurement handle. So the handle can induce the force of different directions such as up, down, left and right. Once the handle is used, we can equip it in a movable panel. So it can be transit to anywhere conveniently. (b) shows us a commerce physical therapy equipment which is named as BTE device. This device can measure most part of the muscle forces in human's body and record them into its computer process module in real time.



(a) (b)

Figure 1. The experimental devices of the bed

Experiment Methods. All the bed test experiments can be divided into 3 sections. In the first and third sections, the subjects are asked to finish some typical force operation experiments; while in the second section, the subjects have to lie in the bed for 45 days. They are not permitted to use their feet to stand in any situations. And all the experiment designs before and after the bed rest in section one and three are same. Finally, after the bed test, we can compare the differences of the force data between the pro and post bed rest to analyze the change rules of the muscle atrophy phenomenon.

(a) (b) (c)

Figure 2. Experiment methods and human body

The experiment processes of the first and third sections are shown in Fig. 2 (a) and (b). The proposed force measurement experiment flows include: 1) the subjects are requested to stand in front of the force measurement device with the distance about one arm. Their feet are fixed by the device of feet restraint. The distance between his two feet is about 30cm. 2) The experimenter dictates each operation action of the experiment content to the subject. Then the subject has to finish these operations using his one or two arms and hands. The main force measurement items are shown in Table 1. 3) During the processing of force measurement, the force sensor will record all the force data to our computer. After each experiment the subject can take a break for several seconds. 4) We use the portable force measurement device (see Fig. 1 (a)) to finish the pre-experiment; while we employ the BTE device (see Fig. 1 (b)) to measure the formal experiment results. 5) When recording the data, the sampling frequency of the software is 2000 per second. And the force record time is 8 second.

Table1 Typical Measurement Items of the Bed Test Experiment.

Experiment Items	**Repeat Times**	**Typical Actions**
Push with Single Hand	1	Push with Right Hand
Pull with Single Hand	1	Pull with Right Hand
Wresting with two Hands	3	Wresting in Clockwise
	3	Wresting in Anti-clockwise
	3	Twist in Clockwise by Right Hand
Twist with Single Hand	3	Twist in Anti-clockwise by Right Hand
Operation with Single Hand	2	Hold with Right Hand
	2	Twist with Right Hand

Once we have measured all the experiment data we can use it to analyze the health state of the subject. Before we present the data analysis method, first we need to introduce the human body model of our experiment. The human body model is shown in Fig. 2 (c). A human body model [5] with 15 segmentations is utilized in this paper. From Fig. 2 we can see that the black circle points in (c) are the joints of the human body model; while the gray rectangle represents the segmentations of this model. The functions of the human body model include: 1) this model can help us to understand the motion state of subject's body. We can use it to define and describe each operation easily. 2) We can also use this model to build the digital astronaut model and use the measurement data to drive it.

Detrended Fluctuation Analysis

The DFA is one of the analysis methods of the fractal series data. DFA method [4] can be utilized to detect the long-range correlations of a non-stationary series. For a data series y_i, $i=1,2,\dots,N$, the DFA formula can be defined by (1) and (2). The scaling behavior of the fluctuation function $F_q(n)$ can determine the change law of the data series: if the data y_i are long-range power-law correlated, the fluctuation function $F_q(n)$ will increase with respect to the law: $F_q(n) \sim n^{\alpha(q)}$. Where $\alpha(q)$ is the scaling exponent. q is the exponent parameter of the fluctuation function $F_q(n)$. We can utilize the calculation result of $\alpha(q)$ to evaluate the attribution of a data set: if the series is a short-range series, it behaves the property of a standard random walk mode. $\alpha(q)=0.5$. If $\alpha(q)<0.5$, the correlation of the data series is anti-persistent. If $\alpha(q)>0.5$ the correlation of the series is persistent. So we can use the scaling exponent to describe the fluctuation and smoothness of the force data.

$$F_n^2(v) = \left\{\sum_{i=1}^{n} x_n^2[(v-1)\times n + i]\right\}\Big/n \quad (1)$$

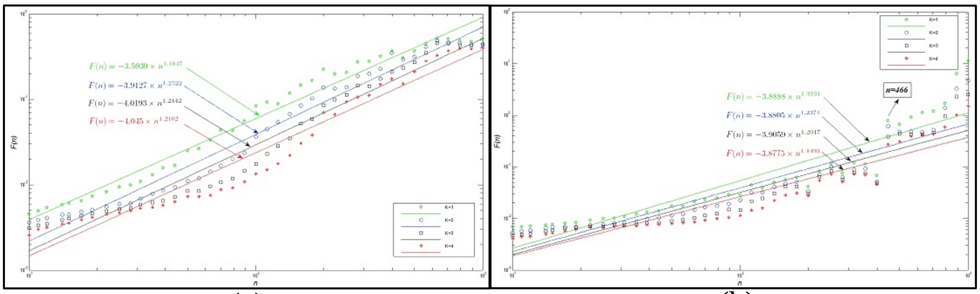
$$F_q(n) = \left\{\left[\sum_{v=1}^{2N_n} F_n^2(v)\right]\Big/2N_n\right\}^{1/q} \quad (2)$$

where $x_n(*)$ means the detrended items of the data series y_i. N_n is the number of the non-overlapping segmentations of y_i.

Results and Discussions

To test the validity of our proposed force measurement method, we design the data analysis method below: 1) we select the endurance force which is segmented from the maximum force point to the stopping point of the force measurement experiment as the analysis force data. 2) We use the DFA method to evaluation the fluctuation of the endurance force data pre and post the bed test. 3) We employ the analysis result of the DFA method to build the relationship between the force data and the health state of the subjects.

Preparation of the Force Data. Some of the experiment data are shown in Fig. 3. In this paper we choose to use the endurance force as the test data to analyze the fluctuation of the typical forces. To get the endurance force data, first we define two data points: the beginning point and the ending point. The beginning point is the force point which has the maximum force value of each typical force measurement experiment. This point always appears after the experimenter orders the subject to implement the typical operation. The ending point is defined as the point that is behind the maximum force data for 8 second. During this time the subject does not permit to rest. Finally, we select all the force points in the duration of these two points as the endurance force data.



(a) (b)

Figure 3. Samples of the DFA result.

DFA Analysis Results. Fig. 3 shows us the DFA analysis results in the logarithm reference frame. (a) is the results of push force before the bed rest, (b) is the results of push force after the bed rest. In this paper, we think this assumption is reasonable: the increasing of the fluctuation of the endurance force indicates the aggravation of the muscle atrophy. Similarly, we also think that the aggravation of the muscle atrophy will cause the increasing of the fluctuation of the endurance force is meaningful. As we know, if people feel tired, their muscle stability will decrease. In this situation when people take some heavy physical actions, their muscle will tremble. So if the muscle atrophy happens, the stability of the muscle will decrease. And the fluctuation of the muscle force will increase. From Fig. 3 we can see that the slopes of the scaling exponent decrease after the bed rest. As we have stated above, we can see that the fluctuations of the muscle force will increase. Then we can deduce that the muscle atrophy happens.

Table 2 shows us the calculation results of the scaling exponent $\alpha(q)$ of the push force and the twist force. In Table 2, symbol K is a control parameter of the DFA method. And symbol q is the exponent parameter (see section III). Here we define the scaling exponent $\alpha(q)$ of the push force, the pull force and the twist force before the bed rest as $\alpha(q)_1$, $\alpha(q)_2$ and $\alpha(q)_3$ respectively. Similarly, we can also define the push force, the pull force and the twist force after the bed rest as $\alpha(q)'_1$, $\alpha(q)'_2$ and $\alpha(q)'_3$ respectively. So, from Table 2 we can see that all these force data have the fractal character and most of the data have the attribution of long term correlation. We also can find that the value range of all these scaling exponents are: $1.0<\alpha(q)'_1<\alpha(q)_1<1.5$, $1.0<\alpha(q)'_2<\alpha(q)_2<1.5$ and $0.5<\alpha(q)_3<\alpha(q)'_3<1.0$. These results indicate that the fluctuations of the push force and the pull force after the 45-days bed rest will increase; while the fluctuation of the twist force after the bed rest will decrease on the contrary.

Table2 Scaling Exponent Comparision of DFA Results

Push Force before Bed Rest					**Twist Force before Bed Rest**				
α(q)	***K=1***	***K=2***	***K=3***	***K=4***	***α(q)***	***K=1***	***K=2***	***K=3***	***K=4***
q=-1	1.28851	1.17212	1.0961	1.04110	***q=-1***	0.78888	0.6783	0.60722	0.58083
q=0	1.29886	1.19371	1.11975	1.05978	***q=0***	0.82158	0.68698	0.61770	0.58780
q=1	1.30357	1.21278	1.14119	1.07798	***q=1***	0.85476	0.69603	0.62883	0.59518
Push Force after Bed Rest					**Twist Force after Bed Rest**				
α(q)	***K=1***	***K=2***	***K=3***	***K=4***	***α(q)***	***K=1***	***K=2***	***K=3***	***K=4***
q=-1	1.09468	0.96152	0.84607	0.73721	***q=-1***	0.96887	0.7895	0.70120	0.62082
q=0	1.10109	0.96952	0.85156	0.74557	***q=0***	0.97651	0.80313	0.71514	0.62916
q=1	1.10617	0.97775	0.85671	0.75504	***q=1***	0.98218	0.81706	0.72843	0.63892

Discussions & Suggestions. From the experiment results above we can see: 1) the discrepancy of the typical forces between the pro and the post of bed test is prominent. That means the muscle atrophy will definitely happen in the zero gravity environment in orbit. So it is necessary to request the astronauts to take some physical exercises periodically. 2) Some analysis results show us the fluctuation of typical force decrease after the 45-days bed rest, such as the twist force; however, after the observation of all the fluctuation data of the typical forces we can conclude that it does not mean the health state of the astronaut is good. Since the human body is a complex system, it will use different muscles to finish an operation task. So we should not be cheated when only parts of these muscles seem to work well. A design of the integrated measurement of the operation force in orbit is still needed. 3) Our experiment proof that the endurance force is a good tool to test the health state of the astronaut. This phenomenon is extensive exist in the force measurement experiment, such as the lower limbs of human body in fact. In this experiment we also analyze the maximum and the minimum forces of all these operation actions. However the discrepancy of these indexes is not prominent for different subjects. So the endurance force and the DFA analysis method are proofed to be one of useful methods to monitor the health state of the astronaut in the future. 4) Since the muscle atrophy phenomenon is inevitable, the research of the human body model (see Fig. 2 (c)) is meaningful because it will guide the design of the exoskeleton device for the astronaut after long time flight journey.

Conclusions

In this paper, an ergonomic bed test is designed to analyze the health state of the astronaut. 8 male subjects are requested to lie on the bed for 45 days all the time. Some typical muscle endurance force data of the upper limb are measured by the force measurement devices pre and post the bed test. The Detrended Fluctuation Analysis (DFA) method is employed to analyze the discrepancy of these typical force data. After this research work, we can conclude that 1) the muscle atrophy phenomenon happens distinctly and the subjects cannot finish some simple action easily. 2) The endurance muscle force before and after the bed test is different remarkably. So it can be utilized to evaluate the health state of the astronaut. 3) Some physical excises are very helpful to maintain the health state of the muscle. These research results can be used as one of indexes to evaluate the health state of the astronaut who stays in orbit for long time flight in the future.

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