Evaluation Research of Joystick in Flight Deck Based on Accuracy and Muscle Fatigue

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Abstract. Human factors have been the main reason of flight accidents, in which misoperation of pilots plays an important role. According to Statistics, in the field of accidents caused by human error accounted for about 80%. The layout design of aircraft cockpit and different controller locations result in different situations of muscle fatigue. Since the situation of muscle fatigue has an effect on the response accuracy, the probability of misoperations increases. The situation of muscle fatigue can be reflected by variables of the sEMG signal. This paper aims to verify the relationship between muscle fatigue and response accuracy based on analysis of sEMG signal. In the experiment, we investigated changes of response accuracy using joystick controller to trace the static object and dynamic object, along with the change of the situations of muscle fatigue. The terminal experiment result can provide information and design method of flight deck to make flight deck safer and more comfortable.

Keywords: human factors, muscle fatigue, response accuracy, sEMG signal.

1 Introduction

It is no doubt that safety is one of the most important criterions to evaluate Civil Aircrafts. From the first flight in December 17th in 1903, the accident rate due to the aircraft equipment failures has declined from 80% to 3% [1], as the technique of aircraft design and manufacture developed greatly. However, according to statistics, the error of flight crew reaches 1to 10 per hour [2], and in the field of aviation system error caused by human error accounted for about 70% to 90% [3-5]. Thus, human factors have been the main reason of fight accidents. However, the traditional ways to increase the reliability and safety of the aircraft can not solve these problems effectively. The research on aviation human factors has been brought to the forefront. [6]

Human-Centered Design can tackle the safety problem from its sources. Cockpits are the main places in which the pilots work, that's to say, majority of human-machine interactions occur in cockpits. Therefore, analysis of cockpit human factors in cockpit design is sure to be the key in aircraft design.

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The situation of muscle fatigue is closely linked with the cockpit comfort. [7] However, the recent design, lack of related muscle fatigue theory, can only refer to empirical data and general rules based on Ergonomics. Muscle fatigue of pilot is the important influencing factor of flight fatigue and cockpit comfort.

Joystick has been applied as controller in A320 which is the first application in civil aviation. Joystick can make the pilots control the aircraft more conveniently and quickly. Nowadays, joystick, as one of the major controllers, is a significant part of cockpit. The aim of this paper is to verify the relationship between muscle fatigue and response accuracy of controlling side stick based on analysis of surface electromyography signal (sEMG signal).

sEMG signal is biological electrical signal of neuromuscular system on the surface of muscles. There is some correlation between sEMG and the active status and function conditions of muscles. Thus, sEMG signal can reflect the situation of neuromuscular activity. The traditional method to analyze sEMG signal is to regard the signal as time function, use a few parameters, such as integral electrical values (Integrated EMG, IEMG) or statistical parameters such as Root Mean Square (Root Mean Square, RMS) to estimate muscle fatigue condition. According to research, when muscles begin to fatigue, the value of IEMG and RMS will increase. [8,9] And in spectral analysis, the method most often used for estimating the spectrum of the sEMG signal was the Fourier transform, partially due to the computationally effective fast Fourier transform (FFT) algorithm. [10] Some spectral parameters, such as Mean Power Frequency (MPF) and Median Frequency (MF) are normally used in analysis of sEMG signal. During static contractions, it has been shown that there is a strong correlation between spectrum characteristic parameters and muscle fatigue, the spectrum shift to the left as the fatigue processes, and the parameters MF and MPF go into a downward trend. [11-12] However, in dynamic fatiguing tasks, it is difficult to get a unified conclusion, because of large changes of MF and MPF. [13]

In this paper, we mainly use the time domain parameters IEMG and RMS, along with spectral parameters MF and MPF to estimate the muscle fatigue status. This paper focuses on the relationship between muscle fatigue and the response accuracy of controlling side stick.

2 Experiment Design

2.1 Participants

30 right-hand dominant volunteers (mean age 21±1.1 years), participated in this experiment. All participants are healthy, and had normal or corrected-to-normal vision. Before experiment, all subjects got enough sleep, and did not have strenuous exercises.

Before placing the measurement electrodes, placement site was identified. The electrode sitewas initially cleaned with sterile alcohol pads to by exerting asufficient abrasive action to avoid impedance mismatch and therefore improve the SNR. Motor points were locatedby means of a stimulator and the electrodes were positionedon the middle portion of muscle belly (short head) parallelto the longitudinal axis of muscle fibers and away from themain motor point. Apparatus

In this experiment, there are three main apparatuses. The first one is a computer, which was used to display visual stimuli on the screen and record the response accuracy. The 22-inch flat computer screen (1680×1050 pixels; 60Hz refresh) was fixed 70cm in front of the participants. An experimental program ran in the computer, to display two kinds of visual stimuli. The first kind is static stimulus, five straight lines, which were going to be traced, were showed on the screen all at once, these lines showing on the screen would last 4 seconds. The second kind of stimulus is dynamic stimulus, the line would appear on the screen every 2 seconds with random directions. There would be five straight lines in one group stimuli.

The second apparatus is sEMG signal measuring equipment—Trigno Hybrid Sensors (fully wireless,Trigno LAB, America 2000Hz), to measure and record the surface EMG signals form right biceps brachii, triceps brachii, and brachioradialis.

A joystick was fixed on a table and held by a participant's right hand, used to control the cursor on the screen. When the joystick was turned left or right, cursor on the screen moved along X axis, when it was pulled or pushed, cursor moved along Y axis.

All software implementations were done in MATLAB 7 with the Signal Processing toolbox 6.0, Statistics toolbox4.0, and Wavelet toolbox 2.2.

2.2 Experimental Procedure

Before the formal experiments, each participant was given a period of time to do the pre-experiments. In pre-experiments, participants were going to understand the experiment content, and be familiar with experimental process and operations.

The formal experiment was divided into two parts: static stimulus experiment and dynamic stimulus experiment. In the static stimulus experiments, volunteers were asked to trace 5 static straight lines on the screen. During the dynamic stimulus experiments, volunteers were asked to do three groups of dynamic stimuli trace, each group contained 5 straight lines. Between the two parts, participants were given five minutes to have a rest to make the fatigue has disappeared.

When the participants were tracing the stimuli on the screen, the computer would record coordinates of each line, and coordinates of trace paths. The surface EMG measuring equipment would record surface EMG signals during the experiments.

2.3 Data Processing

Analysis of Response Accuracy. In the experiments, we can get the coordinates of starting points and end points of the straight lines, and coordinates of trace paths, thus, we can calculate the average distance between the lines and trace path.

From the starting point (a, b) and the end point (c, d), we can get the equation of the line:

$$\frac{y-b}{x-a}=\frac{d-b}{c-a} \tag{1}$$

After simplified, get:

$$Ax + By + C = 0 \tag{2}$$

If a random point on the trace path is (x_0, y_0), the distance from the point to the line is:

$$d = \frac{|Ax_0 + By_0 + C|}{\sqrt{A^2 + B^2}} \tag{3}$$

We calculated the average distance $\bar{d}$ of each point on the trace path. The value of $\bar{d}$ decreases, which means the response accuracy of controlling the joystick increases, vice versa.

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i \tag{4}$$

Analysis of Muscle Fatigue Status. In this paper, we mainly adopt time-domain analysis, along with spectral analysis to estimate muscle fatigue status.

Time-domain analysis is to regard the signal as time function, and then get statistical parameters through analysis, such as shaping and filtering the surface EMG signal, calculating the average rectified value and root mean squared of the signal, and use amplitude histogram, zero numbers, mean square value, the third order moments or fourth order moments as the signal characteristics for pattern classification. Time domain analysis is to describe the time sequence of the amplitude of the signal characteristics, mainly including integral electromyography (IEMG) and root mean square (RMS) value.

Integral electromyography (IEMG) refers to the sum of the area under the electromyographic signal obtained by rectifying filtering per unit time, which is an important means of evaluation of fatigue. Root mean square (RMS) is used to describe a period of time variation characteristics of average myoelectricity, which refers to all the RMS amplitude of this period of time, but it can't reflect the details of the electromyographic signal. Higher amplitude of fatigue electromyographic signal, is bound to cause an increase in the RMS. The time and the degree of fatigue can be identified by comparing RMS of different periods. According to many research results, from the initial state to the fatigue state, the general trend of the time domain value of sEMG is rising in the process of fatigue, which reflects the number of the working motor unit.

$$IEMG = \frac{\sum_{i=1}^{n} |emg_i|}{n} \tag{5}$$

$$RMS = \sqrt{\frac{\sum_{i=1}^{n} emg_i^2}{n}} \tag{6}$$

Traditional spectral analysis method is to transform the time domain signal into frequency domain signal by Fourier Transform; Fast Fourier Transform (FFT) is commonly used in the signal spectrum analysis or power spectrum analysis. The power spectrum analysis of sEMG signal is widely used in muscle disease diagnosis and detection of muscle fatigue; the commonly used indexes are median frequency (MF) and mean power frequency (MPF). Most study in static fatiguing tasks shows that the sEMG power spectrum shift to low frequency when the muscles begin to fatigue, low frequency ratio increased, the proportion of high frequency decreases, MPF and MF would decrease. However, in dynamic fatiguing tasks, it is difficult to get a unified conclusion, because of large changes of MF and MPF.

$$MPF = \frac{\int_{f_1}^{f_2} f \cdot PS(f) \cdot df}{\int_{f_1}^{f_2} PS(f) \cdot df} \tag{7}$$

$$\int_{f1}^{MF} PS(f) \cdot df = \int_{MF}^{f2} PS(f) \cdot df \tag{8}$$

Thus, in this paper, we mainly use the time domain parameters IEMG and RMS, along with spectral parameters MF and MPF to estimate the muscle fatigue status.

3 Results

3.1 Static Stimulus Experiment

In the static stimulus experiments, we used MATLAB 7.0 to process the surface EMG signal, and got the tendency of four parameters (IEMG, RMS, MPF and MF) during experiments.

From figures above, we can find that IEMG and RMS, the two time-domain parameters had a trend of increase, which reflects muscles were in the fatigue state. However, two spectral parameters, MF and MPF did not have an obvious trend.

We can calculate the average distance between the trace path and target lines.

According to this figure, the average distance between the trace paths and target lines did not change a lot or decreased, which reflects that the response accuracy did not have an obvious change.

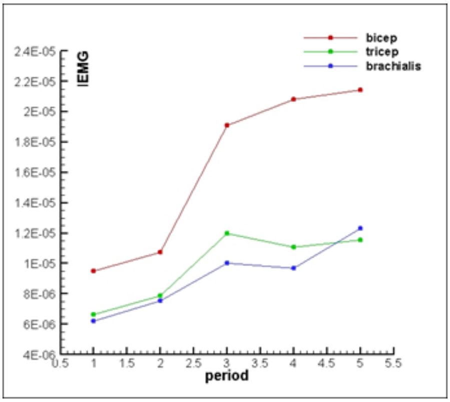

Fig. 1. IEMG in Static Stimulus Experiment

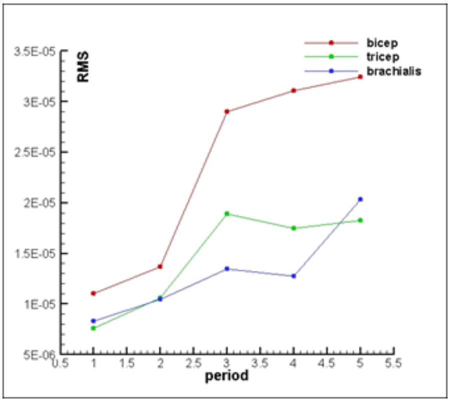

Fig. 2. RMS in Static Stimulus Experiment

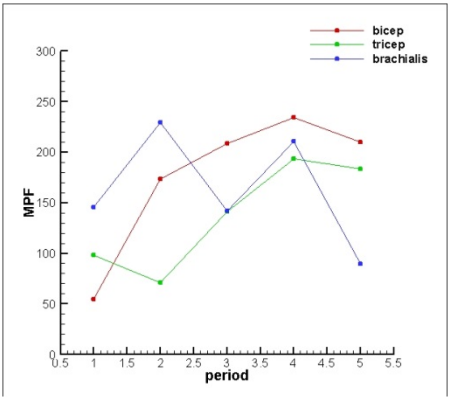

Fig. 3. MPF in Static Stimulus Experiment

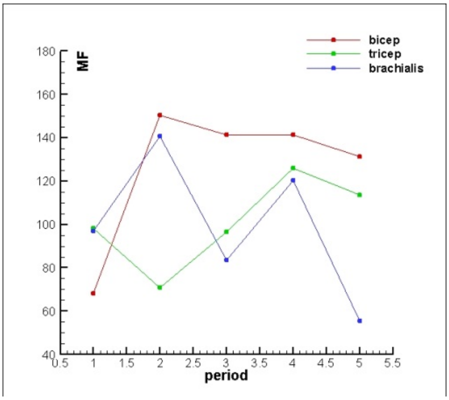

Fig. 4. MF in Static Stimulus Experiment

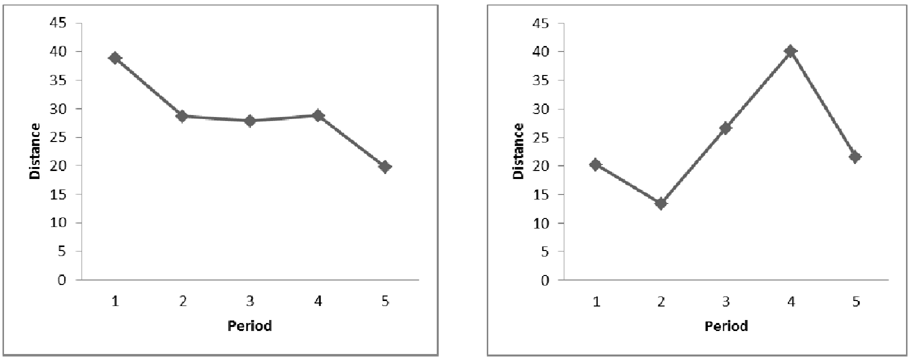

Fig. 5. Average Distance in Static Stimulus Experiment

3.2 Dynamic Stimulus Experiment

The same as the static stimulus experiment, we got the tendency of muscle fatigue parameters as follows.

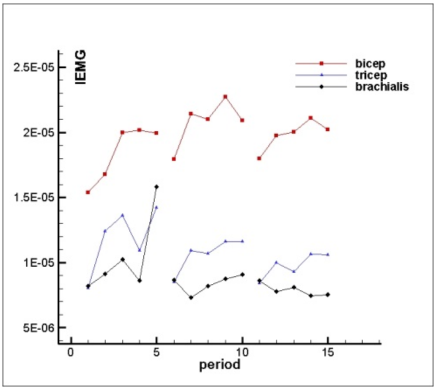

Fig. 6. IEMG in Dynamic Stimulus Experiment

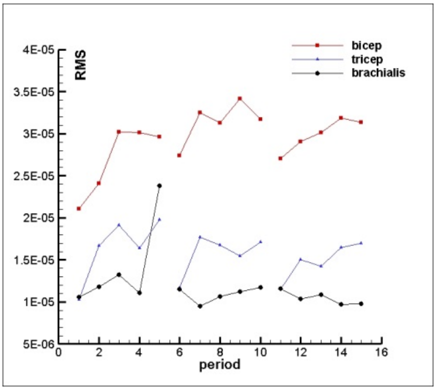

Fig. 7. RMS in Dynamic Stimulus Experiment

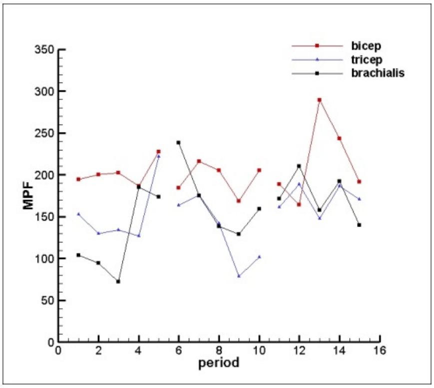

Fig. 8. MPF in Dynamic Stimulus Experiment

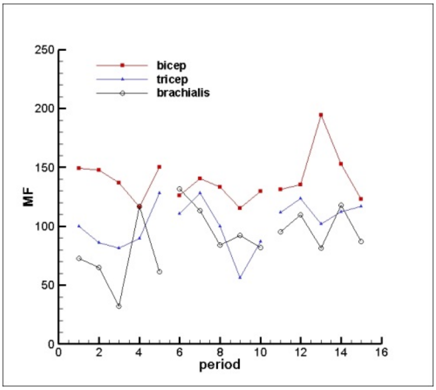

Fig. 9. MF in Dynamic Stimulus Experiment

According to these figures, we can find that IEMG and RMS, the two time-domain parameters had a trend of increase, which reflects muscles were in the fatigue state. However, two spectral parameters, MF and MPF did not have an obvious trend.

Then we calculate the average distance of each group, and got the following figure. In this figure, the average distance between trace paths and target lines increases. It reflects that the response accuracy declined.

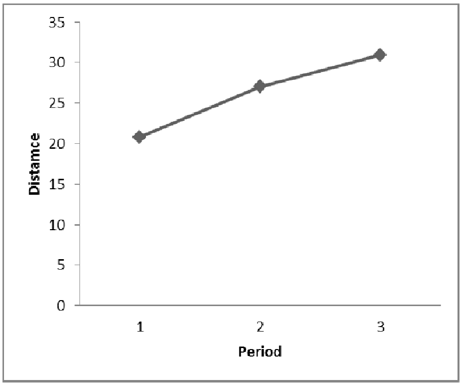

Fig. 10. Average Distance in Static Stimulus Experiment

4 Discussion

Considering the results in Section 3, we can identify that the time-domain parameters, IEMG and RMS, appeared the trend of increasing obviously. This trend reflects that muscles transformed from the normal state to fatigue state. However, the spectral parameters, MPF and MF, did not have an evident tendency. The level of sport intensity is too low (generally smaller than 20% MVC), the spectral parameters (MF and MPF) would not have apparent change.

In the static stimulus experiments, muscles began to fatigue, the response accuracy did not get a unified trend of increasing or decreasing. This situation verified that the muscle fatigue has little influence on response accuracy when people are faced with static stimuli. Some of the participants may have increasing response accuracy, due to they became more familiar with the operations as the experiment went on.

In the dynamic stimulus experiments, when the muscles began to fatigue, the response accuracy would decrease. The experiments verified the correlation between the muscle fatigue and response accuracy.

Because participants were asked to do the static stimuli experiments first, and then take the dynamic stimulus experiments, the operation proficiency may have an effect on the results.

5 Conclusion

In spite of the effect of operation proficiency, there is a correlation of the muscle fatigue and response accuracy. Especially faced with dynamic stimuli, human response accuracy of controlling side stick would decline, as the muscle began to fatigue.

The result of experiments verified that muscle fatigue has an influence on human response. People should pay more attention to the muscle fatigue in flight tasks, to prevent problems in aviation safety because of the low response accuracy.

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