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Analysis of the sitting posture comfort based on motion capture system and JACK software

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***Abstract*—with the development of science and technology, people have higher demand for comfortable seats. However, comfort is a complicated concept to apply in evaluating a sitting chair. There is no established assessment method which could evaluate the sitting chair comfort at present. Most of the current evaluation methods are based on single analysis, and lack multi-analysis of the problem. This paper proposes a new method which integrates investigation methods in real environment and virtual environment. Firstly, Motion Analysis Eagle Digital System is used to capture the body motion of participants, and obtain the human body each joint point in the space. Using a self-developed MATLAB program to analyze the distinct differences on the joint angle and the torques when seated in an Ergokinetic™ Seat chair and seated in a standard office chair. Then, based on the exact data recorded by optical motion capture systems and data processing by JACK software, put the track data files to JACK software, then use TAT report tools to output data and analyze the relative motions data by MATLAB software. Using self-developed MATLAB programs to calculate joint angles, torques and muscle force. Meanwhile, study the muscle comfort index to explore new method to evaluate sitting posture comfort index. The sitting posture comfort index method combined with human body digital model can analyze the siting posture comfort. Also, this research could be applied on optimize comfort level of the body sitting posture.**

Keywords: split-seat chair; sitting posture comfort; motion capture; JACK software; joint angle.

I. INTRODUCTION

Sitting posture analysis has been applied in many areas, including biomechanical, psychological, and security disciplines. Sitting comfort needs could be divided into sitting comfort and discomfort. Several studies have suggested that comfort and discomfort be treated as complementary but independent entities. Similarly, HANCOCK, et al [1], showed that discomfort and comfort are at different stages of needs, the latter being placed at a higher stage than the former. In other studies, comfort was not measured and only a discomfort scale was used with supplemental center of pressure (COP), or interface pressure [4].Seat comfort research mainly based on users' psychological feeling of subjective evaluation and objective evaluation based on motion capture [2], such as analysis of the pressure distribution of the body and measurement of surface electromyography [3], or direct subjective ratings of general comfort checking off features of chairs on checklists, body area comfort rankings, and general comfort rankings [4]. Actually, those methods are often used together [5]. To improve the subjective methods, principles from anthropometry, biomechanics and orthopedics surgery have been applied to seat design [6].Although there are numerous studies on sitting posture comfort, no general agreement has been reached on which method is the best in terms of precision or reliability. Comfort is an area where it is in need of in-depth study, especially involves two soft tissue, in which force distribution is very complex. Obviously, comfort not only relate to the person's own characteristics, and associate with the object itself. So it is complex construct influenced by several factors and it is not simply the opposite of discomfort [7]. Similarly, the test standard of comfort also has a lot of controversy. Even the time needed for each subject to sit in a given seat in order to evaluate its comfort has also been debated. Due to the seat comfort levels related to specific tasks, laboratory comparisons of chairs are often not as meaningful as carefully performed field comparisons [8]. In a static analysis, the center parts of the stress on the body must be determined. At the same time, it is necessary to determine the scope of the joint angle in the activities. The torque and speed vector of movement of the body also need to be evaluated. The analysis of the joint angle and torque helps to evaluate joint ranges of comfort [9].

In some new seat design research, human model is set up to study the influence factors about lumbar support under different motion in the human-chair system, and use the obtained parameters to evaluate the sitting posture comfort [10]. For car seat, some scholars propose the frame component layout design method based on the structural topology optimize design technology [11].Similarly, in terms of comfort evaluation, some scholars use virtual experiment environment to complete vibration simulation. They make use of optical motion capture techniques and digital human modeling software to obtain the body posture parameters, and evaluate the body posture through the analysis of the data [12]. In the sitting position, some scholars establish vertical vibration model with 4 degrees of freedom in view of the upper body based on multi-body dynamics theory, and deduce three theoretic expression which respectively about the displacement, speed and acceleration of the body [13]. In the newest research based on Jack software, using anthropometric parameters to study the influence of joint torque caused by joint angles and external force, and completes the comfort assessment according to the torque [14]. At the same time, within constructing sitting posture

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stress experiment platform, using the MATLAB software to process data and put forward the application model of sitting position state which based on the radial function neural grid [15]. It is necessary to draw a conclusion through exploring parameters in order to define an efficient method to solve comfort assessment [16-17]. The proposed method based on optical motion capture systems, has allowed the system to record the changes of joint angles and tracks of the body [18-21]. Put the data into JACK software, and then use TAT report tools output data and analyzed the relative motions data by MATLAB software. At the same time, based on the raw data, using self-developed program to calculate the joint angles and torques. The sitting posture comfort index method was proposed, this method combined with human body digital model that can analyze the sitting posture comfort.

II. EXPERIMENTAL METHODS

The proposed hybrid system for sitting posture comfort evaluation mainly includes two experimental environments: real and virtual.

A. Hybrid system for sitting posture evaluation

The process of the system is shown in Fig.1, which not only includes the real experimental environments, but also includes the virtual. Among them, the real environments consist of motion capture system, and the questionnaires which survey the human subjective sensation. From the real experimental environment, motion capture system can get authentic test results, which provide raw data input to Jack software. Beyond that, using raw data complete posture comfort evaluation by self-developed software. Under the combination of virtual and real experimental environment, it is possible to evaluate the sitting posture comfort with various human anthropometric parameters.

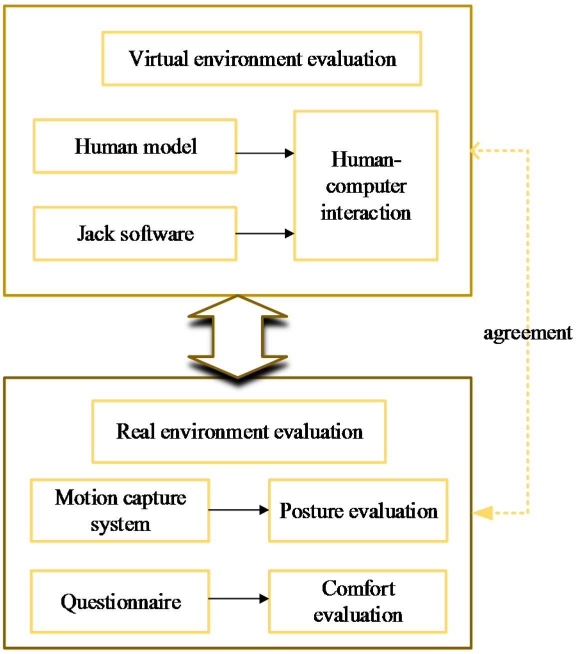

Figure 1. Hybrid system for sitting posture evaluation

B. Subjects and Equipment

1) Subjects

An initial motion study was planned with seven cameras setup in the hope of capturing approximately 20 participant's motion. We recruited a total of 20 students at a British university (10 males, 10 female, mean age22) to participate in this study. Every one of them needed to provide their personal information (Name, Age, Sex, Occupation, Contact Details –Email/Tel.), which was strictly confidential. At the same time, each participant's characteristic data was measured and recorded, such as weight and height. Each participant was also asked to complete 2 full body scans. A questionnaire was also completed with each of the participants.

2) Equipment

The used motion captures system was from Motion Analysis Corporation, USA. The motion data were recorded by an Eagle digital system, which was constructed with seven digital cameras and an Eagle Hub. All of the cameras were connected to a computer terminal and EVaRT Real Time software. This software was used for recording, processing, displaying and post-processing data from the camera system. And the Jack software is a complete system for generating 3D environments or — "virtual worlds" and interacting with them in a powerful graphical environment.

C. Data acquisition

1) Scene Setup

In this study, seven cameras setup was used from the Motion Analysis Eagle system. The motion capture volume was 2 meters wide, 3meters long and 2.2 meters high. Reference markers were placed on the underside of the seat and side of the office desk to record accurate heights of both in 3D space. A preliminary measurement of seat height was measured manually whilst the participants were in seated and standing positions on both chairs. Each subject wore a form-fitting motion capture suit, with 41 reflective markers placed as illustrated inFig.2. With a greater number of markers placed on the back of the subject with the custom marker set, and the constant occlusion from the back rest of the chair, it was vital to have a minimum of 3 cameras placed directly to the left and right of the participant. All cameras located behind the subject were set to the tallest height and arched downward to capture as many of the high/mid back markers as possible. Cameras 1 and 5 were placed at their lowest height to capture as much data below the office desk. The remaining cameras were evenly spaced.

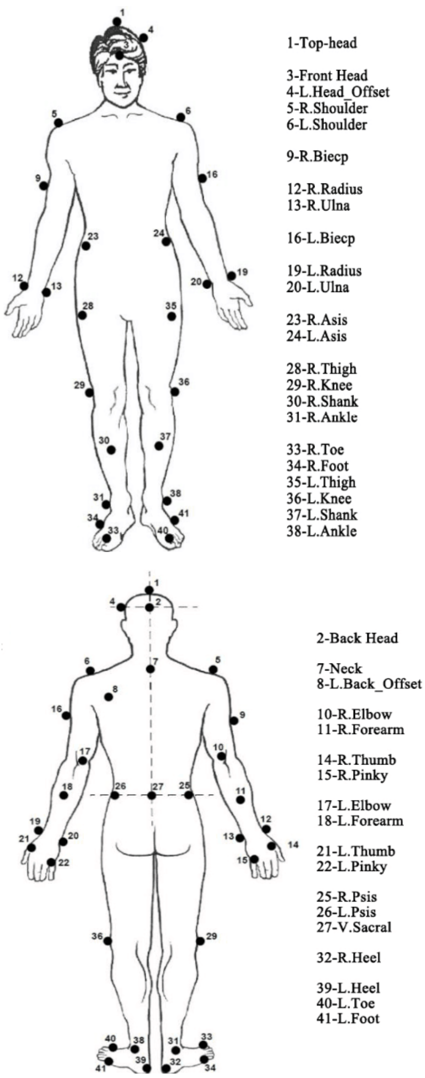

Figure 2. Custom Marker Placement（Jack Marker Placement）

2) Workstation motion tasks

For the motion study, 11 workstation tasks were planned, and each participant was asked to repeat the tasks naturally at normal speed 4 times. Once whilst seated in the standard office chair with their back against lumber support (SOB). Once seated at the front of the standard office chair (SOF). Once whilst seated in the Ergokinetic split-seat chair with their back against lumber support (EGB). Once seated at the front of the Ergokinetic split-seat chair (EGF).

3) Data collection

Data were collected in real time by the motion capture system at a rate of 60 frames per second. The recorded data for each subject were 41 markers coordinates, with an accuracy of less than 0.1mm, in x, y and z directions in 3D space at each frame during play tasks inside the capture volume. These data were saved in the computer terminal as TRC files, and could be played back to show the tasks motion video within the EvaRT software as 3Dpoint clouds (to display the markers only), or 3Dstick figures(to display the markers and the lines which join related markers together).

D. Data processing

1) Export data

a) EVaRT connects with Siemens Jack

EVaRT software is used to record the markers path, and then those obtained TRC data input into JACK software. The Jack mannequin (human figure) should be driven accurately by the motion playing within EVaRT shown in Fig.3. Then an output files will be generated from TAT Reporter. TAT Reporter (The Jack Task Analysis Toolkit is a set of Ergonomic analysis tools that help you design better work areas and evaluate physical tasks.) generate CSV format file ready for data analysis.

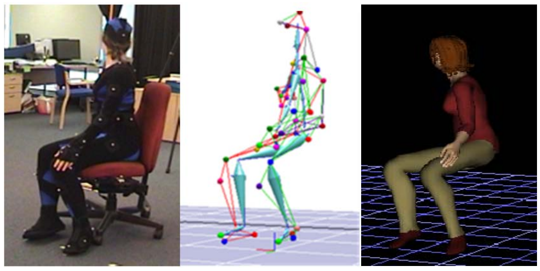

Figure 3. EVaRT connecting with Siemens JACK

b) Export data from Siemens JACK7.1

Record all the motion, then use JACK7.1 TAT tools reporter to export data.

c) Type of Export data

For each workstation tasks and chair types seated in the front and the back, computations of the three types of data. Static data: Include17 Joint Angles (deg), 17 Joint Torques (Nm), 17 Strengths (Nm), and 17 Capable. Back data: Include back of body’s Forces (N), Moments (N), and Muscle Tensions (N). Fatigue data: Include 11 part of body fatigues.

III. DATA ANALYSIS AND COMPARISION

The real experimental environment includes the motion capture system and questionnaires for human subjective sensation and motion capture. The analysis of the raw data was accomplished using a self-developed program in MATLAB. A total of 20 joint angles were evaluated in relation to the sitting posture and body motion tasks. The definition of joint angles was made with reference to ANDREONI G, et al [22], and with reference to other joint angle definition conventions as well. Using a self-developed program in MATLAB, the joint angle were calculated, and compared with the occupational health analysis, like fatigue etc. in JACK software. This paper only introduces upper limbs calculations.

A. The calculation of joint angles

The recorded data for each subject were 41 markers’ coordinates, with an accuracy of less than 0.1 mm, in x, y and z directions in 3D space at each frame inside the capture volume. Connecting three or four points of joint form the joint angle, and then the cosine theorem is used to calculate the angle of space information. The angle of the three relations is shown in Fig 4.

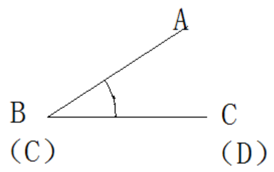

Figure 4. The joint angles

The coordinates of the four points set respectively into $A(x_1, y_1, z_1), B(x_2, y_2, z_2), C(x_3, y_3, z_3), D(x_4, y_4, z_4)$ .The two vectors of AB and CD constitute the required angle. (If there are only three points, point B and point C can be seen as the same point)

$$\boldsymbol{a} \cdot \boldsymbol{b} = |a||b| \cos\theta$$
$$\Rightarrow \cos\theta = \frac{\boldsymbol{a} \cdot \boldsymbol{b}}{|a||b|}$$
$$\Rightarrow \theta = ar\cos\theta \qquad (1)$$

In this formula, $\mathbf{a}$ and $\mathbf{b}$ represent respectively two vectors, and θ is the angle between two vectors. Equation (1) is using to calculate joint angle. After that, the joint Angle of the mean, standard deviation, maximum and minimum values can be calculated. Figure 5 shows the calculated variation range of angles of the shoulder, elbow and wrist in the experiment.

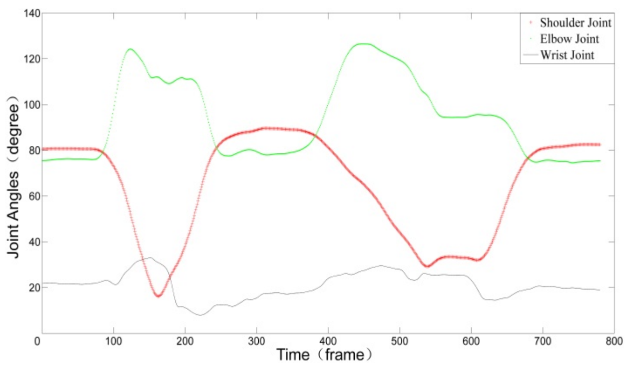

Figure 5. The joint angles

TABLE I. UPPER LIMB JOINT ANGLE DATA（°）

	Experiment data					
Angles	*average*	*SD*	*max*	*min*	*max*	*min*
Shoulder Joint	49.73	16.57	76.85	19.62	84.0	38.0
Elbow Joint	109.96	23.11	141.1	75.64	159.0	126.0
Wrist Joint	26.99	9.22	51.97	10.81	59.0	12.0

B. The calculation of torque data

According to the previous step method which introduces the calculation of the Angle, calculate the angles between the bones and horizontal axis. Consulting basic parameters of the human body based on the anthropometry to obtain the gravity of relevant body parts, and then work out the joint torque based on the torque formula. Then according to the statics balance again, acquire adjacent joint torque. Elbow forearm, for example, this paper introduces related calculation method; it is shown in figure 6 and figure 7. According to the torque calculation formula, the torque data are obtained by MATLAB programming. It will find out the difference of the joint torque between Ergokinetic seat chair and standard office chair while completing the same activity, through the comparative analysis to the final result.

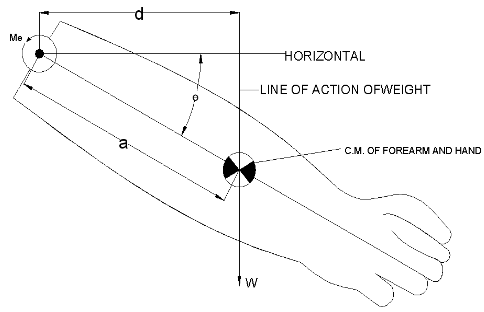

Figure 6. The anthropometric parameters of elbow forearm

$$M_E = d \times W = (\cos\theta \times a) \times W \qquad (2)$$

In (2), $\mathbf{M}_E$ is the elbow joint torque, d is the horizontal distance between forearm and elbows, $\boldsymbol{W}$ is the gravity of the forearm in the anthropometry, θ is the angle between forearm and horizontal axis, a is the actual distance between the forearm and elbow joint.

$$\boldsymbol{R}_E = \boldsymbol{W} \qquad (3)$$

In (3), $\boldsymbol{R}_E$ is counter force of the elbow. According to the static balance, the force which the elbow bears is equal to the gravity.

$$\begin{aligned} \sum M_j &= 0, \\ \sum M_j &= M_{j-1} + [jCM_L \cos\theta_j W_L] \\ &\quad + [L_{jj-1} \cos\theta_j R_{j-1}] \end{aligned} \qquad (4)$$

In (4), $\boldsymbol{M}_j$ is joint torque which come from an arbitrary joint, $\boldsymbol{jCM}_L$ is distance from the joint j to the center of the whole joint chain parts L (It Can be obtained from the anthropometry data) , θ_j is the intersection angle between joint chain part L which from any joint j and horizontal axis, W_L is the gravity of the corresponding parts of the body (which can be obtained from the anthropometry data) , $\boldsymbol{L}_{jj-1}$ is the distance between two adjacent joints j and $j-1$, $\boldsymbol{R}_{j-1}$ is the reaction force in the adjacent joints $j-1$.

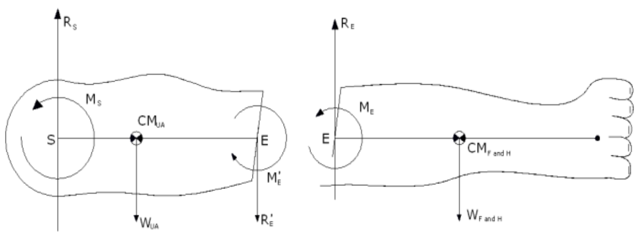

Figure 7. Two-link static analysis of upper arm

$$\sum F_S = 0$$

$$W_{UA} + R_E' + R_S = 0$$

$$R_S = -W_{UA} - R_E' \qquad (5)$$

In (5)，W_{UA} is the weight of the upper arm,R_E' is the resultant elbow force andR_S is a reactive force. The value of R_E' is equal to the vaule of R_E which is the elbow reactive force.

$$\sum M_S = 0$$

$$(SCM_{UA})(W_{UA}) + (SE)(R_E') + M_E' + M_S = 0$$

$$M_S = -(SCM_{UA})(W_{UA}) - (SE)(R_E') - (M_E') \qquad (6)$$

In (6), M_S is a reactive moment, (SCM_{UA}) is the distance from the shoulder of rotation to the center of mass of the upper-arm and SE is the distance from the shoulder of rotation to the elbow center. The value of M_E' is equal to the value of M_E. Using（2）to calculate torque of the specify joint, and then calculate the torque data of adjacent joints based on (3) and (4). Based on the above results, and then using (5) and (6) to calculate torque of shoulder. Similarly, we can use this method calculate the moment of knee and thigh joints. After calculation, the joint torque data can be obtained when the tester complete task2 and task3separately sitting in the Ergokinetic seat chair and standard office chair. The variation of shoulder torque is shown in Figure8 and the variation of elbow torque is shown in Figure9.Both of them are from self-developed MATLAB programs.

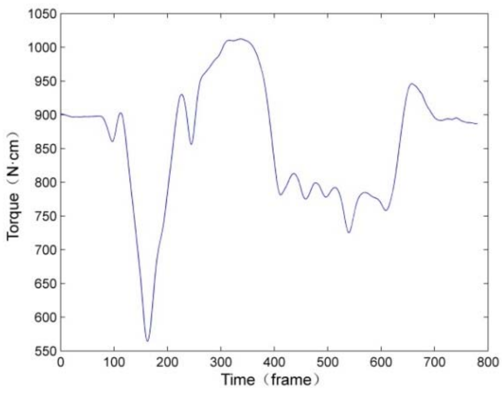

Figure 8. The torque of the shoulder

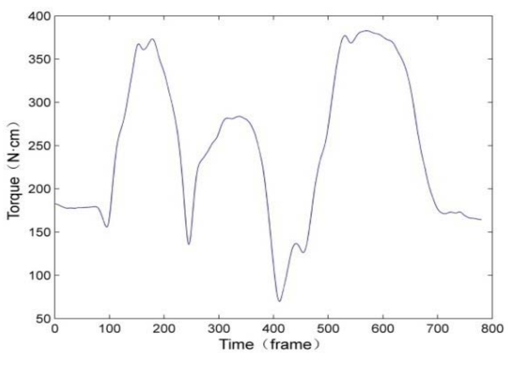

Figure 9. The torques of the elbow

C. The calculation of muscle strength data

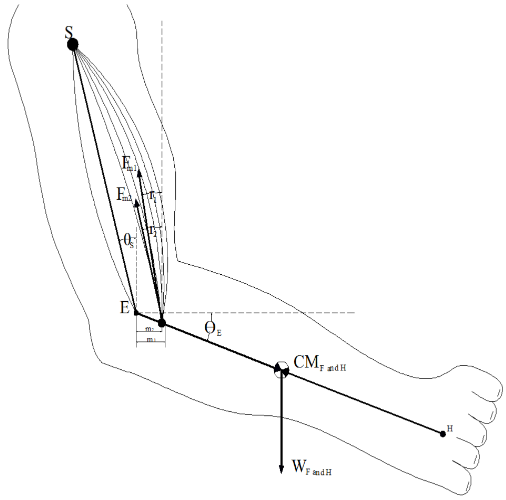

Figure 10. Simplified model of the upper limb muscle strength

The fig.10 showed that F_{m1} is the biceps muscle strength, F_{m2} is the brachial muscle strength, Θ_S is the Angle of upper arm and elbow center vertical axis. Each muscle has its maximum of the human body, a maximum of muscle strength F_i and the maximum muscle stress σ_{max} are related to the (7).

$$F_i = \sigma_{max} \cdot PSCA_i \qquad (7)$$

Work out the elbow torque valueM_E, then get (8):

$$(m_1 \cdot F_{m1} + m_2 \cdot F_{m2}) \cdot cos\Theta_s = M_E$$

$$0 \le F_i \le PSCA_i \cdot \sigma_{max} \qquad (8)$$

Using the MATLAB optimization toolbox Fmincon function, calculate the muscle force$\Sigma(F_i/PCSA_i)^2$.

D. The comfort index model

The actual strength of F_i and F_{imax}can be calculated. So (9) is the ratio of the maximum value.

$$\alpha_i = F_i / F_{imax}$$

$$A_i = \int_0^t a_i dt \quad i=1, 2 \qquad (9)$$

Lactic acid is the main metabolite product of muscle exercise; it is an important sign to evaluate the fatigability of an organism. So, A_i could define the human upper limb muscle fatigue, as in (10).

$$C_i = \int_0^t (1 - a_i) dt$$

$$i=1,2 \qquad (10)$$

The time is an unnecessary outside disruptive factors needs to be avoided.

$$x_i = \frac{C_i}{C_{imax}} \quad i=1,2 \qquad (11)$$

Comfort index of a muscle is x_i, as in (11). C_i is a muscle comfort value for a period of time, C_{imax} for maximum comfort of the muscles. The table Ⅱ showed the human upper limb muscle comfort index.

TABLE Ⅱ. HUMAN UPPER LIMB MUSCLE COMFORT INDEX

C_i	Comfort level
0≤x<0.2	Ⅰ Extremely uncomfortable
0.2≤x<0.4	Ⅱ Very uncomfortable
0.4≤x<0.6	Ⅲ Fairly uncomfortable
0.6≤x<0.8	ⅣA little uncomfortable
0.8≤x<1	ⅤNot uncomfortable

Fig.11 showed the calculated the biceps muscle curves of load rate, andFig.12showed the muscle load rate curve of brachial muscle, both using self-developed MATLAB programs.

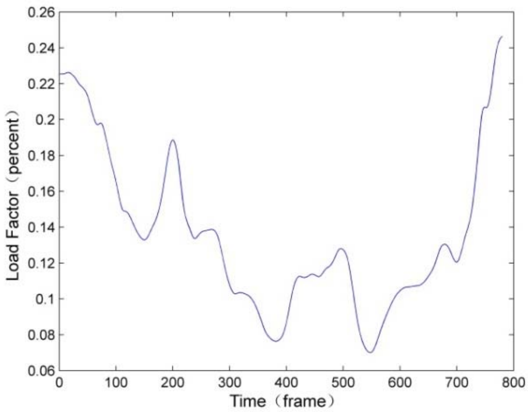

Figure 11. The biceps muscle curves of load rate

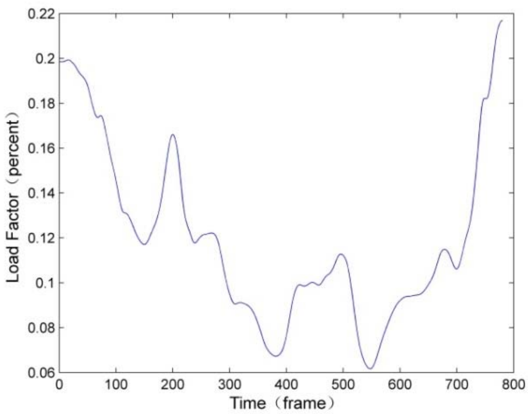

Figure 12. The brachial muscle curves of load rate

Sitting comfort index is based on each muscle's comfort index in human body. The total comfort index is defined through the normalization in Fig.13 . The combination of all comfort index composed of comfort index of limb, head and trunk. It is possible to evaluate the sitting posture comfort with various human anthropometric parameters and questionnaires. We believe that if more distinguishing features can be able to be joined; experimental results will be further enhanced.

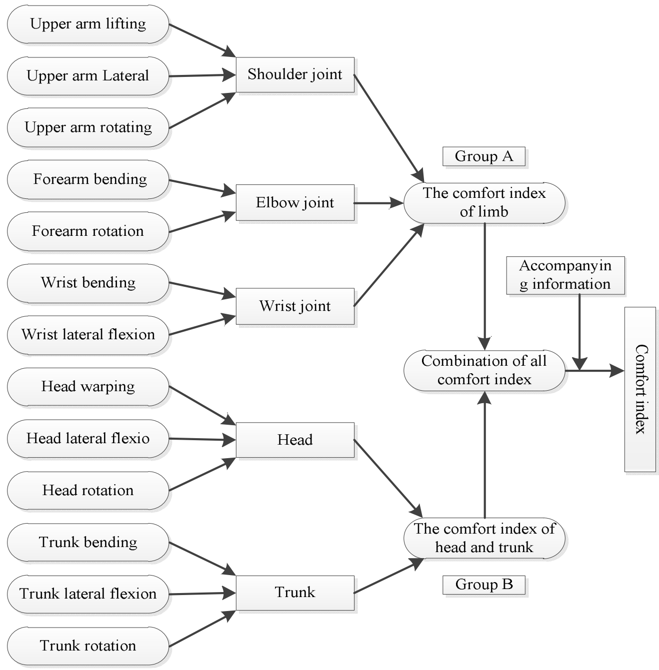

Figure 13. Rule of the comfort index

IV. RESULT

The proposed method using self-developed programs calculate joint angles, torques and muscle force, calculate real-time load rate of human muscles. It will enhance the human comfort index evaluation system. An integrated approach is proposed for digital evaluation of sitting posture comfort which include self-developed programs and JACK software, it used together. Applying this method combined with subjective evaluation questionnaire helps to evaluate sitting posture comfort more accurately. This method is more effective in ergonomic design. The sitting posture comfort index method combined with human body digital model can analyze the sitting posture comfort. The evaluation system could be applied to product design and optimize design process.

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