Upper limb biomechanical study of driving task based on AnyBody software

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With the rapid development of vehicle ergonomics, the mobility and comfort of car significantly improved in recent years. In this study, driving interface model based on Chinese size was built using AnyBody software. Nine different driving tasks were calculated in the model. For each task, the Max-Mus-Act (maximum muscle activity) and the Fm(force of muscle) of the major muscles in the upper limb were calculated. According to the results, the distance from seat to steering wheel, as well as steering wheel torque value under the most comfortable driving posture was obtained. Subjective and objective verification test were designed to verify the feasibility of the driving interface model. Experiments basically verified the authenticity of the simulation calculations. Based on the research, this paper gave recommendations for automotive design and simulation research of driving interface based on Chinese body size.

Keywords: driving tasks, upper limbs, biomechanics, Anybody software, sEMG

1. Introduction

As typical example of human-computer interaction systems, cars draw widespread attention in Ergonomics research. The comfort of upper limbs influence the drivers’ health and driving safety, as upper limbs are the major parts and most likely to be damaged in operating a car. The research of Mathew Ma et al. showed that the steering wheel torque and driving posture are the main factors affecting the upper limbs’ comfort. As the wheel torque determines the extent driving force impose on the wheel, and different driving posture will cause varying degrees of fatigue. This paper aims to study the influence of the two factors, driving force imposed on the steering wheel torque and driving posture, on the comfort of upper limbs, from the view of biomechanics.

At present, subjective evaluation, objective testing and simulation modeling are three main methods in driving comfort research. Subjective evaluation method and objective testing method are used widely in research in previous study as these methods can directly reflect the comfort level of the driver. Subjective evaluation method needs a large number of subjects participated in experiment and the evaluation results are great influenced by the subject’s physical and mental condition during the experiment. Objective testing is only carried on the existing products, which is extensive, time-consuming and costly prototyping (seeing the research of Grujicic, M.). Simulation modeling method is produced based on the development of computer science, and is gradually become the research trend of driving comfort, due to its objective results and repeatability. So the method of simulation modeling has many advantages over traditional methods.

Research of Zhang J et al. showed that models applied to driving simulation are mostly physical models in early research, such as the stick model, the entity split model, the surface model and so on. With the progress of simulation technology, Ramisis software is developed and widely used in automotive ergonomics. It is powerful as not only having real human model but also involving anthropometric typology, attitude simulation and three-dimensional measurement. As the software mainly focuses on the human body reachable area, it lacks the function to research human physiological aspects, such as the musculoskeletal system (seeing the review of Meulen, P. V. D., & Seidl, A.). While AnyBody software makes up for the deficiency, as it considers human skeletal muscle system well. By importing integral human skeleton and muscles model and setting initial parameters, the software can automatically calculate each human joint torques, muscle activity and muscle force. Currently, this software is wildly applied in the field of ergonomics and biomechanics, such as analysis of a femoral-fracture fixation-plate implant, ergonomic analysis of manual materials handling tasks, fatigue research in long-distance driving caused by variable seat design and so on.
Another issue must be considered is that the size of human model applied in the research. As we all know, automobile manufacturing standards are mostly set based on the westerners’ size, which may cause poor driving comfort of East Asians, for the size difference. China has been the world’s largest auto output and sale country since 2009, and the number of Chinese car users is huge. In order to improve Chinese uses’ driving comfort, the research is carried out combined the characteristics of Chinese size standard.

Base on the above literature and analysis, we studied the driving comfort of upper limbs affected by driving force and posture, from the view of biomechanics, using the 50th percentile of the Chinese people dimension imported in the AnyBody software.

2. Modeling and Simulation

2.1 Establishment of Driving Interfaces

The human model based on Chinese adult size was established in the AnyBody software. The parameters of human model size were set as the data of 50th percentile body size of 18-25 year old men referencing GB1000-88 Chinese Adult Human Size. By observing the driving position of skilled drivers, measuring the adjustable distance between steering wheel and car seat, and combining the measurement results of Chinese reaching area, we find that in the case of driving task can be done, elbow flexion angle is close to 0° when the DHS is longest, while the angle is approach to 100° when the DHS is shortest. As the upper limbs posture is mostly rest with the distance between the human trunk and the steering wheel (DHS), three driving postures were set in the simulation, which can represent close, medium and far distance between the trunk and steering wheel. The three postures were driving when elbow flexion angle is 30°, 60°, 90° which presenting near, medium and far distance between the human trunk and steering wheel representatively. The other parameters were set to the average value of a variety of autos, so the steering wheel height was set to 67.2cm, the height of the seat was 28cm, and the wheel type is medium, whose measured diameter was 37.6cm.

When the heights of the steering and seat were set, the positions of human model’s hands and hips were determined at the same time. When the elbow flexion angle was set, the model’s shoulder joint angle was obtained. From the above study, three driving interface models were built, as shown in Figure 1.

![Figure 1. The simulation of three driving interfaces (driving when the elbow flexion angle was 30°, 60°, 90°)](image)

2.2 The Simulation Calculation of Driving Tasks

Before the simulation calculation was carried out, another initial parameter should be set was the force the steering wheel applied to the hands. Three forces were applied to the hands representatively, which were maximum force (Max-F), comfortable force (Com-F) and minimum force (Min-F) applied to the wheel. Three force values were the average value that 10 healthy adult male subjects applied to the steering wheel when they perform the nine driving task (driving with Max-F, Com-F and Min-F when elbow joint flexion angle was 30°, 60° and 90° representatively). The nine average values were imported into the model to calculate, seeing in figure 2. The results of subjects have shown that the steering wheel torques under comfortable forces were 12-14% of that under maximum forces.
The maximum muscle activity (Max-Mus-Act) of the model human and upper limbs’ muscle force data were obtained from the calculation results of AnyBody software. Base on the research of anatomy and physiology, the upper limbs muscles play main roles in driving are deltoid (Del), biceps brachii (Bi), triceps brachii (Tri) and the flexor carpi radialis (Rad). Thus the Max-Mus-Act and the four muscles’ forces were comparatively analyzed in the study.

3. Model Validations Experiments

The verification experiments were designed to verify the correctness of the established driving interface model and simulation calculation results. Validation experiments were performed using the subjective method and objective method; subjective method is used to verify the simulation results of the Max-Mus-Act, while the objective method is used to verify the values of four muscle forces, and objective data obtained by the real-time acquisition of surface EMG signal (sEMG).

10 males were selected for the verification experiment on the premise of not informed anything about the simulation results. All the subjects were in good health, without muscle fatigue, taking no strenuous exercise 24hours before and getting used of the experimental requirement.

3.1 Validation of Max-Mus-Act

Each subject accomplished the nine tasks, which were driving with Max-F, Com-F and Min-F when the elbow joint flexion angle were 30°, 60°, 90°; 1, 2, 3 respectively represent Max-F, Com-F and Min-F. The same in the follow pictures.

The average steering wheel torques imported in AnyBody (A,B,C respectively represent the elbow joint flexion angle 30°, 60°, 90°; 1, 2, 3 respectively represent Max-F, Com-F and Min-F. The same in the follow pictures.)

![Average steering wheel torques](image)

Table 1. Borg Rating of Perceived Exertion Scale (RPE)

<table>
<thead>
<tr>
<th>Number</th>
<th>Level of Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>No exertion at all</td>
</tr>
<tr>
<td>7</td>
<td>Extremely light</td>
</tr>
<tr>
<td>8</td>
<td>Very light</td>
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<tr>
<td>9</td>
<td>Light</td>
</tr>
<tr>
<td>10</td>
<td>Somewhat hard</td>
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<td>11</td>
<td>Hard (heavy)</td>
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<td>16</td>
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</table>
3.2 Validation of the Muscle Forces

The sEMG signals of the four muscles (Del, Bi, Tri, Rad) were recorded while the subjects doing the nine tasks. The sEMG was acquired by Biopac System MP150 bioelectricity acquisition and processing system.

The average rectified value (ARV) of sEMG were selected to be the reference value which is to be compared among the nine tasks, as ARV can be best express the value of muscle force.

4. Results and Discussions

The simulation calculation results and the verification experiments results were compared and analyze as below.

4.1 The Physical Activity Intensity

The Max-Mus-Act values calculated by simulation are seen in Figure 3(a). In the verification experiment, subjects gave their score at the completion of each working condition according to table 1. The mean value of subjective scoring shows in Figure 3(b).

The Max-Mus-Activity of simulation results presents the consistency with subjective scoring in the 9 conditions. When the elbow flexed the same angle, the Max-Mus-Acts under comfortable driving force were significantly less than that under the maximum force, and slightly higher than the minimum driving force. Both the Max-Mus-Acts and subjective scoring decrease with the increase of elbow flexion angles under the comfortable driving force.

Thus, the Max-Mus-Act of simulation, which is consistent with the actual results, can be used for the evaluation of physical activity intensity condition. The correctness and feasibility of simulation results were verified.

(a) The Max-Mus-Act of simulation results
4.2 The Analysis of Muscle Force

The comparison of simulation muscle forces and normalized sEMG ARV results showed as follows.

The deltoid force of simulation results and normalized ARV results of Deltoid sEMG are consistent very much. Under the same driving posture, the muscle forces and ARV values of comfortable driving force were significantly lower than that of the maximum force and lightly higher than the minimum force. The simulation Del force decreased with the distance between steering wheel and seat reducing under the comfortable and minimum driving forces, while the ARV results shows very slight changes with the variety of elbow joint angle. This may be due to the high accuracy of the software. We can draw a conclusion that the simulation results of the deltoid muscle activities could reflect the real working condition above a certain degree.
(b) Normalized ARV results of Deltoid sEMG

Figure 4. The comparison of simulation and validation results of Deltoid

The Flexor carpi radials force of simulation results and normalized ARV results of Deltoid sEMG showed in figure 5. Under the same driving posture, the muscle forces and ARV values under comfortable driving were significantly lower than that under the maximum force, slightly higher than that of the minimum force. With the increase of elbow flexion angle, calculated muscle forces and normalized ARV results increased. This shows that the increase of elbow flexion angle will call the Flexor carpi radials to give more power.

![Figure 4](image_url)

(a) Flexor carpi radials Fm of simulation results

(b) Normalized ARV results of Flexor carpi radials sEMG

Figure 5. The comparison of simulation and validation results of Flexor carpi radials

The biceps forces of simulation and normalized ARV results of sEMG showed in figure 6. Comparing the value of biceps muscle force with above ones, we can see that biceps brachii contributed most in driving. Under the same posture, the muscle force and ARV values showed the same relations with above mentioned muscles. The biceps forces presented upward trend with the distance increasing, while the ARV values showed a little decrease. The reason needs to be found out through further researches. But form the view of anatomy and physiology, when the elbow joint flex angle becomes larger, more muscle units of biceps brachii are activated and called to release power. So the simulation results accord with the view well than sEMG ARV results.

![Figure 5](image_url)
Figure 6. The comparison of simulation and validation results of Biceps Brachii

The triceps muscle forces of simulation were close to 0 N under the nine driving tasks. The amplitude of the sEMG signal was significantly lower than the other three muscles, floating up and down the 0 Volt. The anatomy supports this result, as biceps contributes little to the flexion motion. Therefore, we can work, the calculation results of the triceps simulation calculated is correct and reliable.

5. conclusions

The verification experiments showed that Chinese human model built in AnyBody software by referencing GB1000-88 Chinese Adult Human Size is practicable and feasible. The Max-Mus-Act results and the four main muscles’ (Del, Rad, Bi, Tri) forces obtained by simulation calculation of the nine driving tasks are verified by the subjective evaluation and objective verification methods.

The studies of subjects have shown that the steering wheel torques under comfortable forces were 12-14% of that under maximum forces. The findings have important guiding significance for the individual design of the steering wheel torque. The Max-Mus-Acts under comfortable driving are 15-30% of that under maximum forces. The muscle forces of upper limbs of nine driving tasks gave reference to the health care, and the data could gave comprehensive evaluation by Delphi method in further research.

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References


