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The Virtual Prototyping Design and Evaluation of Ergonomic Gymnastic Based on CATIA

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Abstract

Simulate the computer-aided design of gymnastic device in the pre-development stage by applying CATIA V6 software, and explore the matching degree between gymnastic device design and human body database using the theory and data of Ergonomics. Build the improved model of gymnastic device based on CATIA V6 virtual human data and explore the best evaluation method of man-machine simulation for gymnastic device design after the analysis of man-machine operational processes for computer-aided gymnastic product design and the experiment of human data measurement specimens. The experiment of arm strength gymnastic device for shoulder shows that the application of CATIA V6 software platform not only further shortens the product development cycle and improves the degree of match between gymnastic device and human body, but also enhance the true integration of gymnastic device development and design system from 3D, design and simulation to manufacture.

Keywords: *CATIA V6, Arm strength gymnastic device for shoulder, Posture, 3D Simulation*

1. Introduction

Along with the development of computer technology especially computer-aided design (CAD/CAE/CAM) technology, and with the breakthrough of virtual reality technology and high-performance graphics technology, Ergonomics is gradually moving from calculation by theoretical formula, accumulation of empirical data and simple applied calculation towards computer-aided ergonomic design technology [1, 2]. CATIA V6 provides a variety of efficient ergonomic analysis tools and methodologies which can analyze comprehensively all factors among the man-machine interactive processes and can offer detailed solutions of ergonomic design for designers. Since the use of gymnastic device involves a wide range of body size, the best use of performance between human and products shall be taken into consideration for each size of digital human model [3, 4]. The ergonomic applied research platform provided by CATIA V6 can build 3D models for human body and gymnastic device through the establishment of virtual human body model and the specific applied research in gymnastic device design field of body posture simulation, which improves the efficiency and structural performance of gymnastic device design, and makes a scientific and accurate evaluation on its safety and comfort, thus providing designers with a most efficient and effective way to design humane gymnastic devices.

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2. Ergonomic principles of CATIA V6

Factors such as structure, size, shape, material and quality in each part of gymnastic device may influence the handling, flexibility, stability and comfort in using, so all the design basis is decided by the human data of users. In order to solve the problem among human, machine and environment in the product designing process, CATIA is the first to propose the solutions for man-machine design and analysis [5, 6, 7]. Figure 1 shows the man-machine analysis processes of CATIA. For example, the suitability on human body of gymnastic device's shape and comfort can be evaluated by virtual human body, through which designers can forecast people's working status, man-machine match and rationality of spatial layout. CATIA has four "ergonomic design and analysis modules", including Human Measurement Edit module (HME), Human Action Analysis module (HAA), Human Posture Analysis module (HPA) and Human Builder module (HBR) [8].

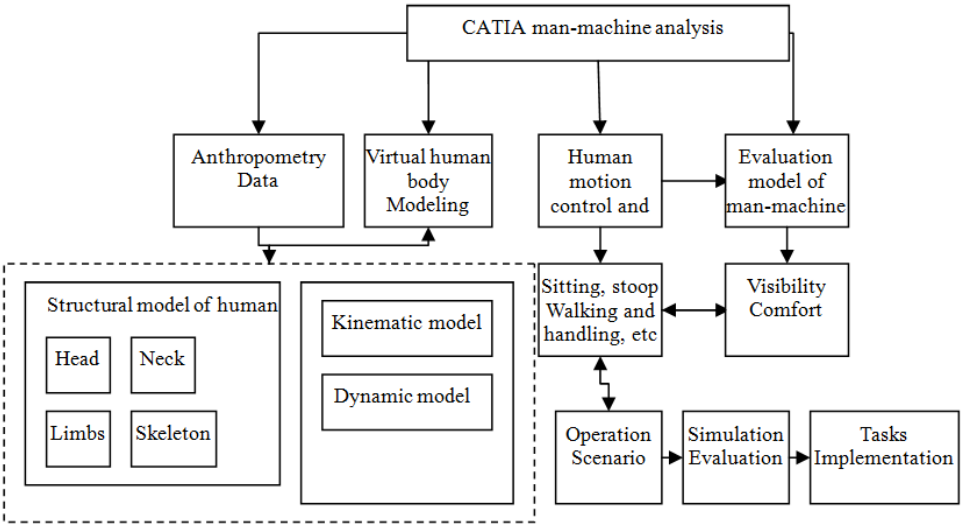

Figure 1. The man-machine analysis processes of CATIA

2.1 Parameterization of standard body type

CATIA provides the creation and management tools of digital virtual human body which can make ergonomic interactive analysis on product in the early stage of product design [9, 10, 11]. Tools provided consist of: the generation of human body model, the definition of gender and height percentage, the generation of ergonomic products, control technology of Ergonomics, action generation and advanced visual simulation. Available human body databases of CATIA V6 include American, Canadian, French, Japanese and Korean; the callable models include those of whole body, right forearm and left forearm; the provided reference points include eye reference point, the default reference point, left foot reference point, right foot reference point, minimum foot reference point and hip reference point [12, 13]. The paper takes female as human body model and eye as reference point in accordance with the specific size of Chinese human body. Human data applies the 95th percentile and the specific data are shown in Table 1.

Table 1. Data of Chinese women's weight, height and bust

Project	Weight (kg)		Height (mm)		Bust (mm)	
Woman (18~55 age)	Meanvalue	Standard deviation	M~v	S~d	M~v	S~d
N-east	55	7.7	1589	51.8	848	66.4
North	52	7.1	1575	51.9	837	55.9
S-east	51	7.2	1575	50.8	831	59.8
Central	50	6.8	1560	50.7	820	55.8
South	49	6.5	1549	49.7	819	57.6

2.2 Size modification of standard body type.

To guarantee the scientificity and accuracy of human data, people are measured either without shoes, or nakedly or with less clothing. However, the product is used by those wearing clothes and shoes, so the measured data shall be modified with heel height and coating thickness added into it, and the final data will be the design basis of product [14, 15, 16]. What's more, the modification value varies against the different dress thickness in different seasons. For gymnastic device, the using environment and way are stationary, so the dress modification value of operator can be determined. The human size can be adjusted according to the used space of gymnastic device. Table 2 lists the different size modification value caused by costume.

Table 2. Size modification caused by costume

Item of posture size	Light summer cloth (mm)	Winter coat (mm)	Modification reason
Height	22 ~ 40	24 ~ 40	High shoe
Seat height	3	11	Pants thick
Height of eye	35	35	High shoe
Maximum width of shoulder	14	45 ~ 70	Coating thickness
Width of hips	13	45 ~ 70	High shoe

3. Evaluation on CATIA V6 gymnastic device

Gymnastic device is a human health-related product, so its design process involves a lot of issues on Ergonomics. This paper takes arm strength gymnastic device for shoulder as an example and illustrates the specific application process of Ergonomics in the field. In various product design processes, the guiding significance of Ergonomics on product design is reflected in the design of man-machine system. Man and machine are two main factors of man-machine system. On the basis of understanding people's main size and different exercising posture, design the product humanely and enhance the effectiveness, comfort, convenience and safety of gymnastic device to the maximum extent [17, 18]. The application of CATIA V6 posture analysis function now makes the test and design process more convenient.

3.1 Establishment of human body model

First of all, the creation of human body model requires the percentile of human size based on the actual application subjects of products. The data of human measurement often takes percentile PK as a position indicator or critical value. A percentile divides all measured values of group or samples into two parts: the measured value with K% is less than or equal to it; while that with (100-K) % is greater than it. The initial stage of design begins from the human body size, the design standard of which is taken as GB/T 10000-1988. Taking men (30-65age) with the percentile of 50% as an example, see human initial models in Figure 2, Figure 3.

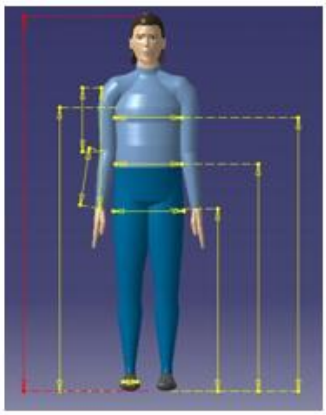

Figure 2. Human Body Model

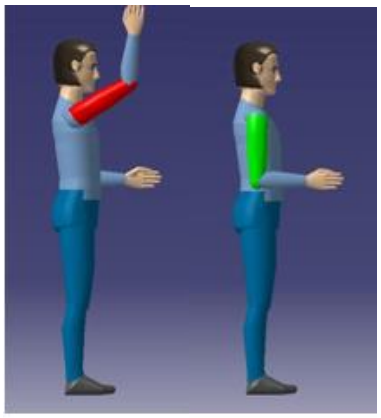

Figure 3. Human Body Model

3.2 Data parameters of arm strength gymnastic device for shoulder

The key factors such as the equipment height, the turning diameter, the thickness of handle and the operating angle shall be taken into consideration in the design of arm strength gymnastic device for shoulder. The height introduction of gymnastic device: Users shall put feet flat on the floor, with calves relaxed and vertical against the floor, and the lower edge of the thigh in conformity with the intermediate position of overall gymnastic device. The height of 1360~1540mm is appropriate for the equipment according to the human size of adult. In order to meet the need of different human sizes, the overall seat height shall be an adjustable structure; The turning diameter: considering the different sizes of men and women as well as the different shoulder curvature of obesity, the turning diameter of handle often takes women's 95th percentile shoulder size as data reference. To guarantee a comfortable operating posture and higher efficiency for users, the monomer diameter shall be between 410~470mm generally when the user's trunk is kept still and limbs in normal active scope, and the recommended value is 450mm; The thickness of handle: the diameter of turning pole and the thickness of flat handle shall not be too large or too small, as it's difficult for hand to grasp if they are too thick and it may result in muscle tension and fatigue if they are too small, and in general, the value of handle is between 20~51mm and the recommended value is 35mm which helps grasp it and drive the runner to move fast. In manipulating, manipulator can get feedback information about the manipulation force, meanwhile, the resistance of 4.1kg is better when doing tilt trailing manipulation fitness; The operating angle: the best active angle of hands in relaxed status while manipulating is lateral 60° when manipulated by one hand, lateral 30° from both left and right sides when manipulated by two hands and lateral 0° from both left and right sides when manipulated accurately and easily by two hands. See Figure 4, the general structure of arm strength gymnastic device for shoulder.

Figure 4. Common structure of arm strength gymnastic device for shoulder

3.3 Man-machine test analysis of arm strength gymnastic device for shoulder

Because of the current technical limitations, arm strength gymnastic device for shoulder, as a specially designed fitness product for shoulders, still remains in the stage of active training. The existing products in the market are basically divided into two types: one is rim-type gymnastic device (to realize rehabilitation through radius of hands' rotation); the other is rocker-type device which allows both circular motion and pendulum movement. Both two types have their restrictions on use. Rim-type: it is mainly used in public places, and its active angle and scope cannot be adjusted freely; rocker-type: it is applied by professional rehabilitation center, also considered as individual rehabilitation machine after illness and it is difficult to handle as there is no adjustable inclination angle. In CATIA V6, product models and human body models are placed into one environment. Simulate people's operation mode and make ergonomic analysis on product after the calling-in of well-designed new models.

In the man-machine test of new product, the 50th percentile woman is chosen for human body. As the modification value of human shoes, like 20mm, should be added into the test process, a 20mm height plate will be put under human body. Figure 5 shows the height relations between human and rehabilitative apparatus in use. The height of rocker is adjustable in accordance with the individual physiological characteristics so as to adapt to the usage of different groups of people.

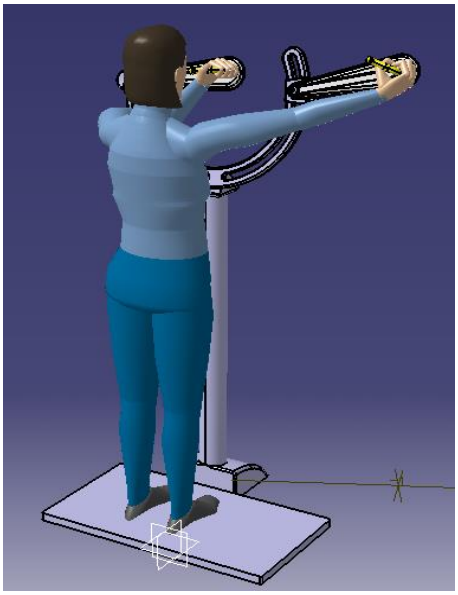

Figure 5. A high degree of test

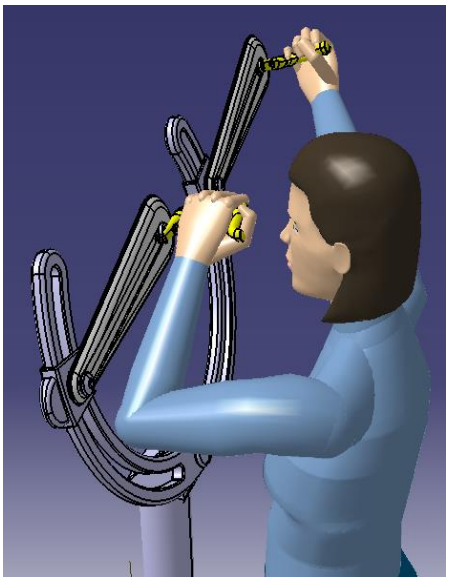

Figure 6. Hand test

As shown in Figure 6, it reflects specifically the direct touching of human hand and rehabilitative apparatus during the operation. There into the yellow part is hand rotator. By grasping it, people get the best contact to it with maximum stress surface and even force. The entire operation is controlled by rehabilitee, with non-slip treatment at the extremity of rotator to prevent the slip-off from hands.

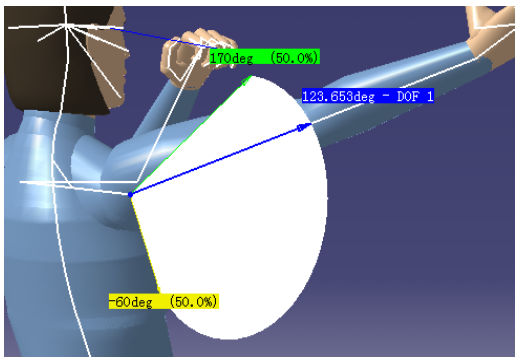

Figure 7. From the point of maximum shoulder

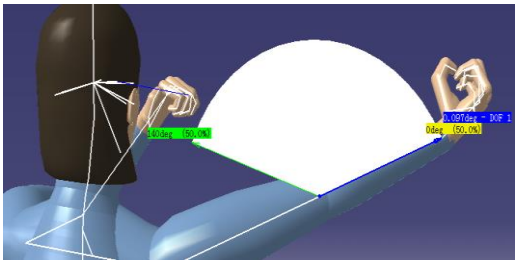

Figure 8. Point of the elbow

Figure 7 shows the arm angle when people move to the maximum distance. The arm active angle is among 170 ~ -60° between the yellow and green part. The blue part is the current arm angle which is approaching the maximum active range. As the height of rocker is adjustable, users can adapt to different individual training requirements by adjusting the height of it.

Figure 8 shows the elbow angle which is in its minimum value and force when the elbow is straight. The straight training of elbow is quite necessary for patients with shoulder disease or elbow hyperplasia.

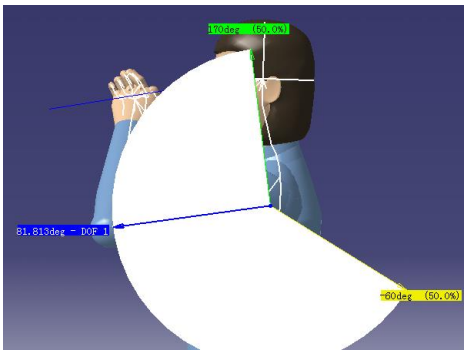

Figure 9. Arm angle

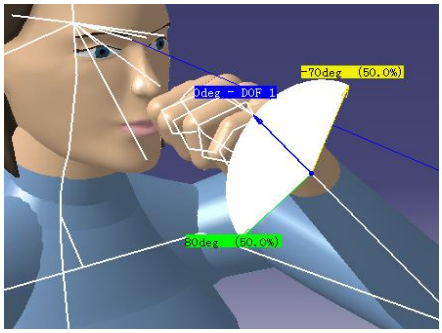

Figure 10. wrist angle

As shown in Figure 9, when doing bicep curls, user is in the most comfortable location and will be relieved the pain in the course of training with 82° shoulder angle. As shown in Figure 10, 0° wrist angle eliminates the burden on wrist and reduces the fatigue of user in bicep curls.

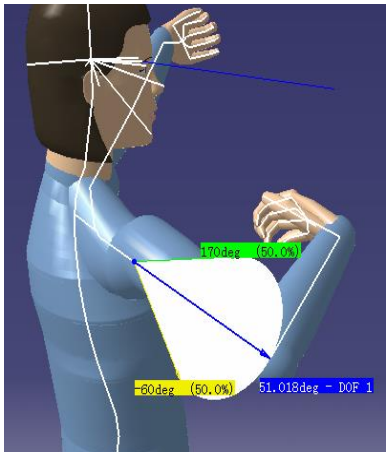

Figure 11. Shoulder angle

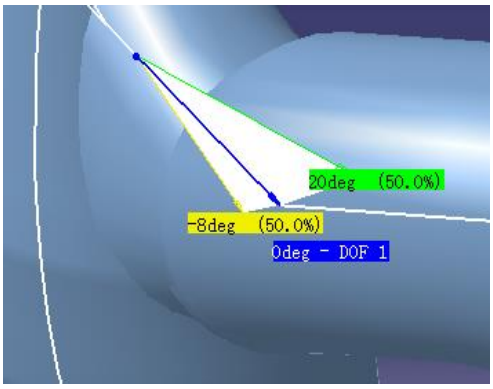

Figure 12. Shoulder angle

As shown in Figure 11 and Figure 12, the comfort is the best when shoulder angle is 0°.

3.4 Man-machine evaluation analysis of arm strength gymnastic device for shoulder

Arm strength gymnastic device for shoulder is a kind of training apparatus designed for human body building and fitness enhancing. Therefore, it is a kind of special product closely related to human body, just like bicycle. When designing gymnastic devices, designers should take "human and gymnastic device" into primary consideration. The coordination between the two is the key of a successful designing of arm strength gymnastic device for shoulder. Designers shall focus more on ergonomic research when developing and designing arm

strength gymnastic devices for shoulder in the future, which is the first feature to be analyzed and studied in the developing trend of designing a gymnastic device based on effectiveness. In the ergonomic design of the arm strength gymnastic device for shoulder, the specific human parameters as well as the following points shall be taken into consideration:

Whether the functions of arm strength gymnastic device for shoulder match with human size, body shape and force application? The arm strength gymnastic device, closely related to human size, contacts with human body directly and its main function is to restore human performance. Therefore, the inherent size of human and the range of application force shall be considered when man-machine is designed.

Whether the arm strength gymnastic device for shoulder accommodates to the human usage habits of it and is easy to handle? Although the function of the arm strength gymnastic device for shoulder is to conduct fitness training on human body, and sometimes the design of training modes is not quite appropriate for the usage habits of users, the design should also conform with human usage habits and modes for those body parts that needn't training. For example, when the arm strength gymnastic device for shoulder is designed, the handle contacted with human hands should accord with the size and usage habits of common people.

Whether the accidental injury in handling and hazard by incorrect use are prevented? While designing the man-machine of arm strength gymnastic device for shoulder, we should fully understand the applied way of training and set scientifically the movement time, frequency and the force of application according to different requirements in different stage of exercise in order to prevent body injury caused by over-exercise. For the incorrect manipulation by users, there should be some alarm design on it.

Whether the operating units of the arm strength gymnastic device for shoulder are practical and functional? The overall training effect of the arm strength gymnastic device for shoulder, including the expected performance of man-machine design and the fully function of every operating unit as well as the reliability and utility of operating units, shall be fully considered.

Whether the functional elements are clear and easily recognized in semantic expression? An important part in man-machine design is that of the interface. And the key of hardware interface design for arm strength gymnastic device for shoulder is whether the usage mode and function expressed by gymnastic device can be recognized clearly and correctly by users, and it's mainly reflected in the semantic expression of functional structure design, color design, material quality and texture design. As a fitness product designed for shoulder training, the arm strength gymnastic device for shoulder still remains in active training stage, and its evaluation basis and standard can only be tested in practical use because of the technical limit.

However, through the analysis of relations between "human and gymnastic device", the system chart of man-machine evaluation can be taken as the basis and standard of evaluation, as shown in Figure 13.

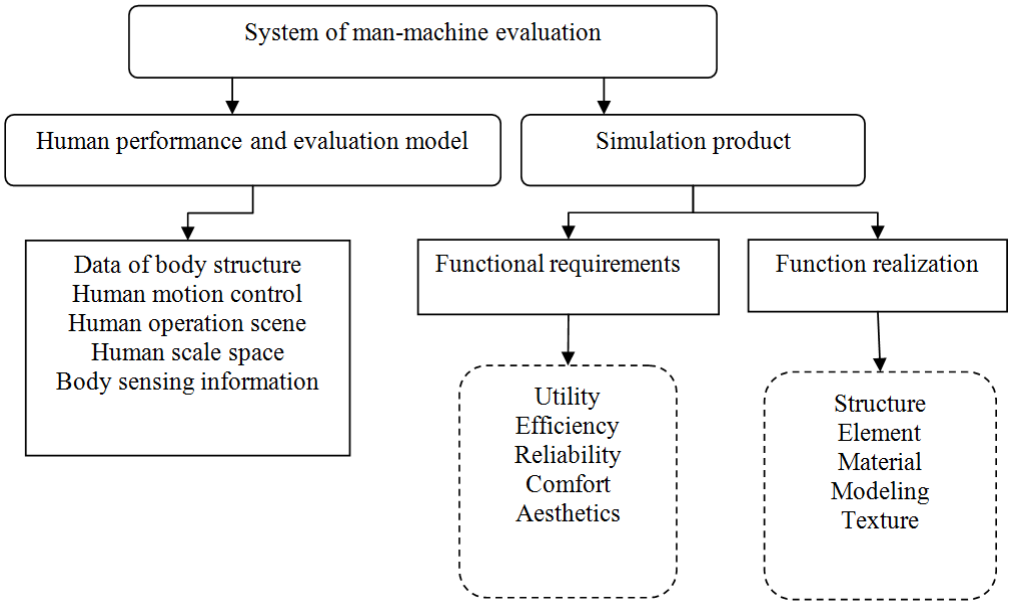

Figure 13. System chart of man-machine evaluation

Make quantitative evaluation on human posture and make quanlitative evaluation on the im provement of gymnastic device for shoulder through the "ergonomic analysis and design" mo dule of CATIA software platform. Table 3 is the evaluation criterion of posture.

Table 3. Evaluation criterion of human posture

Color and grade	Evaluation and suggestion	Comfort level
(Green) 1~2	Long-time maintenance and repetition of the posture are unsuitable	Acceptable
(Yellow) 3~4	Further study on the change of posture is necessary	Further study is necessary
(Orange) 5~6	Study and change the posture as soon as possible	Change the posture as soon as possible
(Red) 7	Study and change the posture immediately	Change the posture immediately

Segments	S...	Resu...
All (all DOF)		76.4
All		76.4
Selected		
Favorite		
Arm	L	53.9
	R	58.7
ForeArm	L	81.5
	R	79.0
Other		
Neck		96.9
Hand	L	93.6
	R	68.2
Thoracic ...		99.7
Customized		

Figure 13. The main parts of the body evaluation

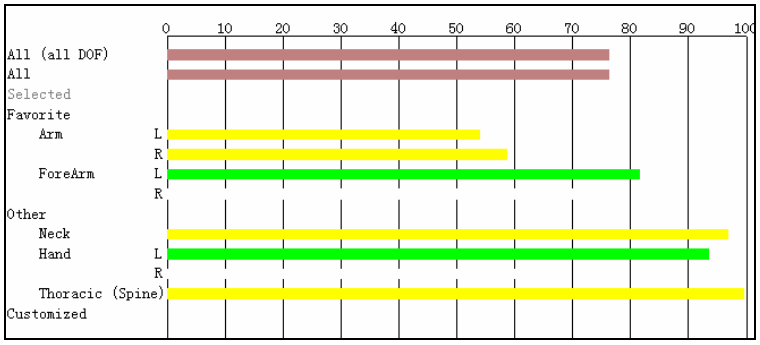

Figure 14. Histogram display

Segments	S...	Ang...	Resu...	Score
All (all DOF)			76.4	
All			76.4	
Selected				
Favorite				
Arm	L	0.01	53.9	0.0
	R	0.59	58.7	80.0
DOF1	L			
	R	0.89	98.4	80.0
DOF2	L	1.02	83.0	90.0
	R	1.06	6.9	0.0
DOF3	L	0.01	24.8	0.0
	R	0.59	70.8	80.0
ForeArm	L	1.05	81.5	90.0
	R	1.83	79.0	40.0
DOF1	L			
	R	1.83	79.0	40.0
DOF3	L	1.05	81.5	90.0
	R			
Other				
Neck		0	96.9	90.0
DOF1		0	96.4	90.0
DOF3		0	97.3	80.0
Hand	L	0.13	93.6	80.0
	R	1.17	68.2	30.0
DOF1	L	0.13	87.1	80.0
	R	1.17	68.2	30.0
DOF2	L	-0.51	100.0	80.0
	R			
Thoracic ...		0	99.7	90.0
DOF2		0	99.7	90.0
Customized				

Figure 15. Body parts of the detailed evaluation

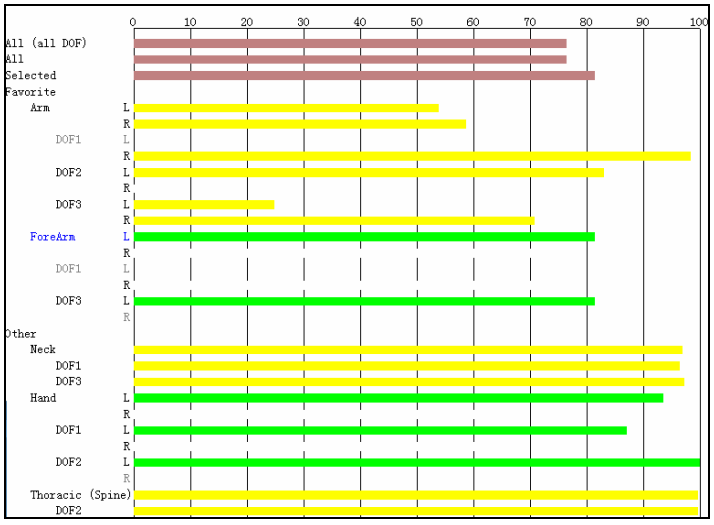

Figure 16. Histogram display

Results: Figure 13-16 reveal the analysis data of human comfort; Figure 13 shows the average comfort evaluation index of left arm & right arm, left forearm & right forearm, left hand & right hand, neck and chest; And Figure 14 is the histogram display of the above index; Figure 15 shows the detailed data analysis evaluation of three different freedom degrees of each joint as arm (three freedom degrees), forearm (two freedom degrees), neck (two freedom degrees), hand (two freedom degrees) and breast (one freedom degree); And Figure 16 is the histogram display of the above evaluation. According to the above columnar scoring, we can see that the green and yellow parts are relatively high in index and better in user's comfort, which complete the requirements of simulation design and provide significant reference value for similar gymnastic devices.

4. Conclusion

The design research of computer-aided gymnastic device based on man-machine mainly analyzes issues of whether the gymnastic device products meet the requirements of human size and whether the product design and operating requirements are reasonable through the application of CATIA V6 man-machine analysis module, thus optimizing the design of product. The experiment shows that the whole body and postures of human can be tested and analyzed repeatedly, comprehensively and systematically from various aspects so as to evaluate the comfort of user in use; to check, record and replay the postures of the whole body or body parts by comparing the reflected comfort with the published comfort in database; to determine the comfort and operability of human body; and to make man-machine analysis on gymnastic device products by using HPA and HAA, thus establishing a computer-aided gymnastic device product design system based on Ergonomics.

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