Optimal Design and Verification of Standing-up Motion Assistant Machine

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Abstract. Standing-up motion assistant machine is a new type of assistant device for the care and motion of the semi-disabled, which can replace the manual motion mode to a great extent and reduce the workload of the care-givers. After a detailed analysis of shortcomings of the structural design of the existing standing-up motion assistant machine in the practical application in elderly institutions, this paper proposes a design scheme and mechanical structure of the hanger. The optimized product is verified based on ergonomics theory. Results show that the design scheme and structure of the hanger of the motion assistant machine proposed in this paper can satisfy the requirements of occupant comfort on the premise of ensuring safety, as well as effectively expand the application of the standing-up motion assistant machine in elderly institutions of varied facility levels.

Keywords: Motion assistant machine; Structural design; Ergonomics; Optimization Method.

1. Introduction

As a rehabilitation medical equipment, the standing-up motion assistant machine can replace the traditional human labor, and help the elderly or disabled to move freely in different scenarios, such as the mutual transfer between bedroom and bathroom, or between bed and wheelchair. It can also function as rehabilitation training equipment. The advantages of it are high efficiency and strong stability, and it has brought great convenience to patients and care-givers¹. However, with the popularization and application of standing-up motion assistant machine in the market, some potential problems during use have emerged.

The current research and development of motion assistant machine still focuses on its safety and reliability. Most of the motion assistant machine products in the market are simple in structure, single in function and low in automation². By far the greatest demands are solutions to the comfort of the motion assistant machine and to bring better experience to the disabled. Therefore, it is necessary to investigate the characteristics of the disabled in the process of practice, and conduct scientific analysis on the problems affecting the current user experience. Scientific, personalized and targeted design principles to optimize the design should be adopted³. This is also the priority of the design optimization of the standing-up motion assistant machine in the future.

2. Research Background

As shown in figure 1, the main components of standing-up motion assistant machine are lifting mechanism, variable angle chassis, stable handle, shift handle, knee pad and adjusting lever⁴.
In order to understand the factors that affect the user experience and carry out the corresponding design optimization, Sijiqing homes for the elderly in Haidian District, Beijing, was taken as the experimental site to carry out field investigation in which a total of 10 Chinese-made motion assistant machines were put into use, and 96 disabled elderly people who voluntarily participated in the experiment were taken as the research objects. After the elderly tried the standing-up motion machines according to the experimental process, they were asked to complete the predesigned user satisfaction questionnaire. The research results were recorded statistically, as shown in figure 2.

Figure 1. Structure of standing-up motion assistant machine.

![Figure 1](image_url)

Figure 2. Investigation on the existing problems of standing-up motion assistant machine.

According to the statistical results, the major factors that affect the user experience are as follows:

1. Due to the limitation of mechanical structure, users must adjust their bodies to the lifting posture with the front facing the body before using the motion assistant machine, which markedly increases the workload of care-givers and cannot be applied to various lifting scenarios;
② After use, it is time-consuming and laborious to put the hanger belt fixed on the boom back to the original position.

3. Optimal Design of Mechanical Structure

The optimal design of the mechanical structure is conducted in order to solve the existing problems. After consulting the literature[5] and analyzing the existing machines, it is expected to design a detachable hanger as shown in figure 3 to solve these two problems with personalized and targeted design principles.

As shown in the figure, the hanger bearing can rotate 360 degrees with the hanger rod as the centre. The connection between hanger and hanger rod is a damped rotor. The reason why rolling bearings are not selected is that the friction force at the contact of rolling bearings and hanger is extremely small, and a little force will drive the hanger below to rotate greatly. We hope to avoid this phenomenon in the process of shifting, so as to avoid danger. Due to the large friction force at the contact, the damped rotor will drive the hanger to rotate at a certain angle according to the needs of the scenarios. In this way, the problem ① mentioned in the second section is well solved: During use, only the hanger rod needs to be rotated to drive the hanger belt to rotate to adapt to various lifting postures, and care-givers are no longer needed to assist the user in adjusting the lifting posture.

![Damped rotor and gear](image)

**Figure 3.** A detachable hanger.

Aiming at problem ②, a buckle design is proposed to meet the use requirements. When using the optimized motion assistant machine, the user only needs to fix the lanyard of the hanger belt on the buckle, and pull the belt up to remove it after use, which spares the tedious work of fixing and removing the hanger belt on the boom before and after use. Furthermore, the knee pads of the motion assistant machine are optimized, and it is expected that the comfort of leg will be significantly improved. The overall structure of the optimized standing-up motion assistant machine is shown in figure 4.
Figure 4. Structure of the optimized standing-up motion assistant machine.

4. Verification Based on Ergonomics

4.1. Introduction to Ergonomics
Ergonomics is an emerging discipline category, which takes many disciplines including work physiology, work psychology, anthropometry and human mechanics as its research approaches and means, and conducts a comprehensive study on the factors affecting the structure, function and psychology of human body. Ergonomics has adopted numerous research methods of different categories. Among which some have been adopted from the best methods of anthropometry, psychology and other disciplines and still can be seen in present researches, thus forming a unique system, some have been borrowed from related disciplines, while most of them have been created for the purpose of application. The study of this paper employs the following ergonomic methods for verification:

1. Measurement method
The method used to study the physical characteristics of human body in ergonomics is called measurement method, including but not limited to measurements of strength, volume, scale, dynamics, and other physiological changes of human body.

2. Survey method
Survey method refers to testing a certain group of people. It adopts predesigned survey content and objectives to conduct questionnaire or interview on the target group, while adopting necessary objective tests (including physical tests and psychological tests). Statistics and feedback of the target group are recorded and analyzed.

3. Experimental method
Experimental method refers to setting a specific experimental environment, operating according to certain steps, and recording and analyzing the results.

4. Sensory test method
Sensory test is to evaluate the physical attributes of products by sensory functions, so as to find the most satisfactory product attributes for consumers and provide decision-making basis for production and business activities. The testing process must involve advanced psychological activities, such as...
evaluating the comfort and satisfaction of product attributes which indicates consumers’ emotion, memory, association, thinking and so on[7].

4.2. Methods and Verification
This section analyzes the comfort experience of optimized products through experiments. Firstly, carry out the test design, including interview questionnaire and the grouping of participants; then organize the test in sequence and interview the participants; after that, record the results and statistics and analyze the effect optimization.

4.2.1. Test design. In order to directly and clearly understand the real user experience of the optimized products, sensory test method in ergonomics is employed to verify the optimization results qualitatively. Combined with the previous user feedback, seven key questions affecting the user experience were selected for questionnaire design, as shown in table 1:

| Questions and suggestions | Content (on a 5-point scale) |
|----------------------------|----------------------------|
| I                          | Can different lifting postures be basically realized? Please rate your experience. |
| II                         | Is the installation and disassembly of hanger belt convenient? Please rate your experience. |
| III                        | How does your back feel during use? Please rate your experience. |
| IV                         | How does your thigh feel during use? Please rate your experience. |
| V                          | Is the process of lifting smooth and flexible? Please rate your experience. |
| VI                         | How does the space for use feel? Please rate your experience. |
| VII                        | Please make a comprehensive evaluation during use (the place where you feel uncomfortable or satisfied, where out of the expectations, etc.) and score. |
| VIII                       | Please offer your valuable suggestions for the further optimization of this product. |

(Description: The scoring adopts a 5-point scale on which 4.5-5.0 points denote very satisfied, out of expectations and excellent comfort; 4.0-4.5 points denote satisfied and general comfort; 3.5-4.0 points denote basically satisfied and average comfort; 3.0-3.5 points denote dissatisfaction and poor comfort; 2.5-3 points denote very dissatisfied and relatively poor comfort; scores below 2.5 denote extremely dissatisfied and unqualified products.)

15 participants were selected as samples of this test. In order to make the results universal, there were great differences in height and weight among the participants. Generally, the height ranges from 160cm to 185cm, and the weight ranges from 45kg to 90kg. According to the height and weight, the participants were divided into three groups: A, B and C. The information of participants is shown in the table 2.
Table 2. Basic information of participants.

| Group | Number | Name  | Gender | Height (cm) | Weight (kg) |
|-------|--------|-------|--------|-------------|-------------|
| A     | 1      | Xu*   | Female | 160         | 45          |
|       | 2      | Zhang*| Female | 163         | 53          |
|       | 3      | Chen* | Male   | 168         | 50          |
|       | 4      | Cheng*| Male   | 170         | 60          |
|       | 5      | Li*   | Male   | 170         | 61          |
| B     | 6      | Li*   | Male   | 171         | 70          |
|       | 7      | Luo*  | Male   | 173         | 59          |
|       | 8      | Mei*  | Male   | 174         | 60          |
|       | 9      | Li*   | Male   | 175         | 57          |
|       | 10     | Xu*   | Male   | 175         | 80.5        |
| C     | 11     | Zhao* | Male   | 178         | 65          |
|       | 12     | Wang* | Male   | 179         | 70          |
|       | 13     | Yi*   | Male   | 182         | 82          |
|       | 14     | Li*   | Male   | 183         | 86          |
|       | 15     | Wang* | Male   | 185         | 81          |

In addition, the use of the standing-up motion assistant machine designed in this paper involves the man-machine-environment interaction. Therefore, before the test, the influence of the machine as well as the environment needs to be considered. The general scenario is the mutual transfer between wheelchairs, beds, toilets or other seats. Hence the height standard size of these products should also be considered in the test design. According to the investigation data, the production standards of these products in the Chinese market are shown in table 3:

Table 3. Standard production size of products.

| Product name   | Bed       | Toilet   | Wheelchair | Other seats                  |
|----------------|-----------|----------|------------|------------------------------|
| Standard production height (unit: cm) | 46-50     | 42-60    | Back seat height: 41 Front seat height: 43.5 | Easy chair for rest: 38-45 Office chair: 43-50 |

Based on the factors of size mentioned above, we used an armless chair with a height of 45.4 cm to simulate real-world applications such as beds and toilets. The participants sit in different positions before the test to ensure the simulation of real-world scenarios.

4.2.2. Verification. Simulation of real-world scenarios of the motion assistant machine was conducted on the premise of ensuring safety. 15 participants used the hanger belt to test the machine by adjusting different lifting postures. During the test, the participants operated in a standardized way, simulating the elderly who were disabled in lower limbs and only relying on the strength of the boom to lift, so as to ensure the effect.

(1) Group A (160cm-170cm):
Figure 5. Test of group A.

(2) Group B (170cm-175cm):

Figure 6. Test of group B.

(3) Group C (175cm-185cm):
Figure 7. Test of group C.

The interview and investigation of sensory test were conducted right after the test of each participant according to the predesigned questionnaire, so as to obtain their truest and most intuitive feelings\textsuperscript{[9]}.

4.2.3. Analysis of verification results. In the above test, a total of 3 groups of 15 participants were tested, and they were asked to score each index on a 5-point scale. The statistical results were compiled into Table 4 as follows:

| Table 4. Scoring results of participants. |
|------------------------------------------|
| **Group** | **Question number** | **I** | **II** | **III** | **IV** | **V** | **VI** | **Comprehensive score** |
|-----------|---------------------|-------|--------|---------|--------|------|-------|-------------------------|
| A         | 1                   | 4.5   | 4.3    | 4.4     | 3.8    | 4.0  | 4.2    |
|           | 2                   | 4.2   | 4.6    | 4.5     | 4.0    | 4.1  | 4.3    |
|           | 3                   | 4.0   | 4.7    | 4.3     | 3.7    | 4.1  | 4.1    |
|           | 4                   | 4.3   | 4.4    | 4.3     | 3.8    | 4.2  | 4.2    |
|           | 5                   | 4.0   | 4.5    | 4.1     | 3.5    | 3.9  | 3.8    |
|           | **Average score of group A** | 4.2 | 4.5 | 4.3 | 3.8 | 4.2 | 3.9 | 4.2 |
| B         | 6                   | 4.1   | 4.3    | 4.2     | 3.7    | 3.8  | 3.7    |
|           | 7                   | 3.9   | 4.2    | 4.3     | 3.5    | 4.2  | 3.8    |
|           | 8                   | 3.8   | 4.4    | 3.9     | 3.6    | 4.0  | 3.5    |
|           | 9                   | 4.1   | 3.9    | 4.1     | 3.4    | 4.0  | 3.7    |
|           | 10                  | 4.0   | 4.1    | 4.0     | 3.5    | 3.6  | 3.5    |
|           | **Average score of group B** | 4.0 | 4.2 | 4.1 | 3.5 | 3.9 | 3.6 | 3.9 |
| C         | 11                  | 3.8   | 3.8    | 3.7     | 3.3    | 3.8  | 3.6    |
|           | 12                  | 3.5   | 4.1    | 3.9     | 3.2    | 4.0  | 3.2    |
|           | 13                  | 3.9   | 4.0    | 4.0     | 2.8    | 3.6  | 3.4    |
|           | 14                  | 3.7   | 3.7    | 3.9     | 3.1    | 3.7  | 3.5    |
|           | 15                  | 3.5   | 3.6    | 4.1     | 2.9    | 3.5  | 3.0    |
|           | **Average score of group C** | 3.8 | 3.8 | 3.7 | 3.3 | 3.8 | 3.6 | 3.6 |
To make the results more visual, a bar chart was drawn as follows:

![Bar Chart]

**Figure 8.** User experience of groups A, B and C.

From the above table and bar chart and through the comparative analysis of the data, we can see clearly that:

1. The average score of the first item “completion of lifting in different postures” is 4.0, which shows that the problem ① has been remarkably improved after optimization, and it has been confirmed that the motion assistant machine with optimized mechanical structure can basically realize smooth lifting in different postures.

2. The average score of the second item “simplicity of operation” is 4.2, with the highest satisfaction in this test. It indicates that the problem ② has been basically solved, and the new buckle design that can save time and effort in the installation and disassembly of hanger belt has achieved the expected effect of optimization.

3. According to the statistical results of other items, the optimized standing-up motion assistant machine can not only solve the above problems, but also ensure good user experience, and has basically met the requirements of ergonomics for comfort.

However, some other factors affecting the user experience were found through this test. It can be easily found out from the bar chart that in the longitudinal comparison of almost every item: scores of group A > scores of group B > scores of group C. And the participants of groups A, B and C are divided according to their height in ascending order. In order to explore whether there is a direct relationship between height and user experience, we take height (unit: cm) as the horizontal axis, and the comprehensive score of participants as the vertical axis, and draw a line chart as follows:
It can be seen clearly from figure 9 that with the increase of height, the comprehensive score shows an overall downward trend. According to the reality, with the increase of height, the users’ body shape will generally increase, resulting in an increase in friction force between the hanger belt and human body, and the force bearing area of the hanger belt is certain, hence the heavier the person, the greater the pressure, the stronger the squeezing feeling and the poorer the comfort. Therefore, in the subsequent design optimization, the hanger belt should be the focus.

5. Conclusion
Based on the feedback of model application in elderly institutions, this paper puts forward a new design scheme and mechanical structure of the hanger of motion assistant machine. Based on ergonomics theory and testing method, a comprehensive test method combining measurement, investigation, experiment and sensory test was designed. The verification and evaluation of the design scheme and structure were completed through a test in three groups of 15 participants. The test results show that the hanger designed in this paper can meet the requirements of human comfort, as well as expand the application of standing-up motion assistant machine in elderly institutions of varied facility levels.

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