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Design optimization of rehabilitation equipment based on ergonomics

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ABSTRACT
with the aging of the population and the rising prevalence of chronic disease, the demand for rehabilitation medicine is growing. The poor man-machine adaptability and insufficient safety of traditional rehabilitation equipment lead to poor rehabilitation effects. Ergonomics provides a theoretical framework for solving such contradictions. Therefore, this paper will discuss how to optimize traditional rehabilitation equipment based on ergonomics to meet market needs better. It is hoped that the analysis of this paper will provide a strategic reference for the intelligent transformation of rehabilitation equipment to promote the optimization and sustainable development of medical equipment design and provide stronger support for rehabilitation people.

KEYWORDS
ergonomics; rehabilitation equipment; human-computer interaction; dynamic feedback

Globally, the number of patients with dysfunction due to aging, chronic diseases, and accidental injuries is increasing. As an important tool for functional recovery, rehabilitation equipment directly affects patients' rehabilitation outcomes and quality of life. At present, most of the mainstream equipment in the market follows the design idea of mechanical transmission and fixed support, which is not adaptable to the human motion system; in the process of rehabilitation training, there are many problems, such as the lag of force deviation monitoring and the lack of joint protection mechanism. Some equipment also causes skin damage in the use process, directly affecting rehabilitation. Ergonomics emphasizes integrating human anatomical characteristics, movement rules and psychological cognitive characteristics into product design and improves system efficiency by reducing use load and operation complexity. Based on this principle, the design of rehabilitation equipment should meet the requirements of mechanical support, exercise guidance and risk prevention and control simultaneously to reduce the training fear of patients and shorten the rehabilitation period. Therefore, this paper will analyze the existing problems of rehabilitation equipment and explore the design strategy of rehabilitation equipment in line with the principles of Ergonomics; it is expected to provide a feasible scheme for solving the insufficient man-machine adaptability and potential safety hazards of traditional equipment.

1 The theoretical basis of ergonomics in the design of rehabilitation equipment

1.1 The Basic Principles of Ergonomics

The basic principle of ergonomics is to design and improve the working environment by understanding the human body's structure, function and physiological response to improve the working efficiency and comfort. From office furniture design to aerospace equipment, ergonomics has various applications in various fields. The design of rehabilitation equipment based on ergonomics should meet the requirement that the equipment's supporting structure and motion trajectory be consistent with the natural action mode of the human body. The designer should fully combine the anthropometry data through the adjustable parts or modular structure to adapt to individual differences, thereby reducing the fatigue or secondary damage caused by the size mismatch rocket. Human Ergonomics also focuses on the influence of human perception and behavior habits on the use of equipment. The human body receives external information through sensory systems such as vision, tactile sense, and proprioception and converts it into neural signals to guide action execution. Based on this, the operation interface of rehabilitation equipment should conform to the user's intuitive reaction, and the feedback mechanism of the equipment should be synchronized with the rhythm of human motion [1]. This design can reduce the user's cognitive burden, improve the action's consistency, and promote the adaptive training of the neuromuscular system.

1.2 Analysis of human-computer interaction needs of rehabilitation equipment

The human-computer interaction needs of rehabilitation equipment are reflected in how to make up for the users' physiological dysfunction through technical means and meet their psychological and behavioral characteristics. Some users have limited motor ability due to myatrophy, arthrodesis (joint fusion) and nerve injury. The equipment needs to provide accurate mechanical support and action guidance to help users carry out rehabilitation exercises within a safe

range. The rehabilitation interactive system needs to monitor the user's electromyogram signal in real time, identify the abnormal movement pattern, and correct the deviation through instant mechanical feedback. The interaction needs at the psychological and cognitive levels are also critical. Long-term rehabilitation training easily leads to a decrease in users' enthusiasm, and the lack of obvious training effect will cause anxiety. The rehabilitation equipment needs to maintain the user's psychological input through interactive design: the color gradient bar is used to display the strength output, the dynamic icon is used to simulate the completion of the action, and the specific sound effect is issued after the user's action reaches the standard, to strengthen the positive incentive. The control command of rehabilitation equipment should be simple, the key function buttons should be highlighted, and the operation process should conform to the intuitive mode of"Trigger-response" so that the user can focus more on executing the action to improve the training efficiency and safety.

2 Analysis of the existing problems of rehabilitation equipment

2.1 Inadequate fitness between equipment size and human body

The core reason for the lack of fitness between the size of rehabilitation equipment and the human body lies in neglecting the dynamic needs of the human body in the design process. The human body in rehabilitation training will be accompanied by muscle contraction, joint activity and center of gravity transfer to produce continuous spatial changes. However, the support structure of traditional rehabilitation equipment is mostly designed based on static anthropometric data. For example, the seat height setting of the sitting training equipment refers to the static ischial tuberosity spacing, ignoring the soft tissue deformation during the human pelvis's forward tilt and spinal column's scoliosis and the imbalance of the pressure distribution. As a result, local blood circulation disorder and skin pressure sore occurred during the use of rehabilitation equipment. Another reason for the lack of fit between the size of the equipment and the human body is the contradiction between the diversity of the human body and the standardized production model [2]. The mass production of rehabilitation equipment uses the universal size template, but the physiological characteristics of the user group are quite different. The bone strength and muscle endurance of young and elderly patients are significantly different from those of adults, but most equipment is not designed for special groups. Moreover, the progressive functional decline caused by chronic diseases requires rehabilitation equipment to adjust parameters, providing users with continuous rehabilitation services automatically. However, existing designs are mostly based on fixed size thresholds and lack the adaptability to adjust according to the user's rehabilitation progress automatically.

2.2 Complex operating procedures and insufficient feedback

In order to highlight the functional advantages of many rehabilitation equipment, the operation steps are designed to be too cumbersome, and the user needs to switch the mode and confirm the state repeatedly. This multi-step operation is a burden for ordinary people. For patients who need rehabilitation training, it is more difficult to complete. Some patients experience memory decline and slower reaction times due to the disease. Complex operating interfaces can confuse them, often requiring a significant amount of time to understand the function of each feature, which directly reduces the equipment's efficiency. The problem of insufficient feedback stems from the way information is transmitted. Rehabilitation training needs to know whether the action is standard and whether the force is appropriate in real-time. However, many rehabilitation equipment only display numbers and charts through the screen; users have to stop their movements to view the data, which affects the consistency of the training. Feedback delays are also a common problem, with rehabilitation equipment often not alerting users until they have made a certain amount of movement errors, missing the best opportunity to correct, and preventing users from adjusting their movements promptly, thus affecting the training effect.

2.3 Imperfect Safety Protection Mechanism

At present, most rehabilitation equipment can only monitor basic physical indicators, such as whether the weight is excessive or whether the equipment is tilted, and can not detect the actual changes in the user's body. The equipment often can not recognize the uneven muscle force, abnormal joint movement angle or sudden convulsion of the user in time, and the physical conditions of different patients are obviously different, but the equipment usually adopts a unified safety standard, the protection threshold is not adjusted according to the individual situation, and the user faces the risk of accidental injury in the application of rehabilitation equipment. The safety function of rehabilitation equipment relies on the sensor to trigger the emergency mechanism. However, it takes some time for the signal to be transmitted to the mechanical execution link[3]. When the user is out of balance, the support structure takes more than half a second to activate after the sensor detects the abnormality and the body state has been irreversibly damaged, while when multiple

risks occur at the same time, the system of rehabilitative equipment may lead to the conflict of protection instructions due to the confusion of priority judgment. These implementation problems reduce the effectiveness of safety protection.

3 The optimization strategy of rehabilitation equipment design based on ergonomics

3.1 Strengthening the adjustable design of human body size

The optimization of rehabilitation equipment based on ergonomics needs to improve the adaptability of rehabilitation equipment, and a preset multi-dimensional adjustment module according to different users' height, arm length, shoulder width, and other key physical parameters is needed to provide a fine adjustment scheme. A fine adjustment scheme is provided according to different users' height, arm length, shoulder width, and other key physical parameters. The adjustment range should break through the fixed interval limit of traditional instruments so that children and adults with special body types can find the appropriate position through sliding rails and telescopic brackets. The adjustment process needs to adopt a combination of physical identification and electronic prompts and feedback on the current state synchronously through light guidance and screen animation to help users quickly judge whether they meet the adaptation standards and reduce the time consumption of repeated adjustment. Rehabilitation equipment needs to be equipped with real-time monitoring and automatic correction functions, continuously tracking the user's posture changes and automatically fine-tuning the contact surface's angle, height, or pressure distribution. For long-term used equipment, it is necessary to gradually relax or tighten activity restrictions according to the rehabilitation stage, avoiding excessive intervention in the early stage while meeting the needs of capability enhancement in the later stage. Ultimately, through the combination of hardware adaptation and intelligent algorithms, rehabilitation equipment can shift from passive adjustment to active adaptation, reducing the burden of manual operation and better supporting the rehabilitation needs of users

3.2 Simplified interface and enhanced dynamic feedback

The operation of rehabilitation equipment should be simple, and the setting of interactive interface functions should be clear. Among them, the core functions are concentrated in a single main control area, and different modes are clearly distinguished by color block partition, icon semantic design and status indicator. The touch panel needs to adopt a hierarchical flat design, and the high-frequency function adopts physical or floating buttons. In the feedback of rehabilitation training data, only the necessary training parameters and progress tips are retained, and the visual elements, such as the dynamic progress bar, are presented. According to the needs of special groups, the interactive interface of rehabilitation equipment should add operation modes such as voice command awakening and gesture sliding switching to ensure that users with different cognitive abilities can independently complete the basic settings to apply this equipment to rehabilitation training. In addition, rehabilitation equipment also needs to integrate a multi-channel perception system through pressure sensors, inertial measurement units, and bioelectrical signal acquisition equipment. The movement trajectory, muscle activation degree and physiological index fluctuation of the user are synchronously monitored, and the instant brake protection is triggered for high-risk conditions such as joint hyperextension and center of gravity imbalance to protect the user's safety [4]. The tactile sense informs the user of different vibration frequencies and intensities. The vision feedback needs to use augmented reality technology to display the force distribution and correction suggestions on the equipment screen. The auditory sensation feedback needs to be designed with different prompt scales to meet the rehabilitation needs of the users; the urgency information is conveyed through the change of pitch and rhythm so that the rehabilitation training is smoother and more effective.

3.3 Introduction of intelligent safety braking and protection structure

The design of rehabilitation equipment based on ergonomics should meet the safety requirements. The equipment should integrate high-precision sensors and dynamic algorithms to monitor the user's real-time action trajectory and force intensity through the preset human biomechanical model to identify abnormal motion patterns, and intelligent safety braking is realized. The braking execution unit should be directly coupled with the moving parts to synchronize the intervention action with the occurrence of risks. At the same time, the braking threshold should be adjusted according to the user's rehabilitation stage, and the protection threshold can be strengthened in the initial stage. In the later stage, the restrictions can be gradually relaxed to stimulate the user's autonomous control ability. The operation interface of the device needs to integrate the visualization module of the braking state and display the activation of the protection mechanism in real-time through different colors and dynamic icons to help users understand the device intervention logic and adjust the training strategy. The support area of the rehabilitation equipment needs to adopt bionic buffer materials and deformable skeletons. The contact surface load is sensed in real-time through the pressure distribution

sensor, and the local hardness and curved surface radian are automatically adjusted to avoid using local pressure too high to lead to skin damage[5]. An intelligent tension adjustment system is developed for truncal orthosis equipment, which dynamically adjusts the belt's tension according to the breathing rate and muscle contraction state. The rehabilitation equipment should also set up a double safety mechanism; when the main protection mechanism fails, the manual release valve is automatically activated to minimize the risk of accidental injury.

4 Conclusion

In summary, rehabilitation equipment based on ergonomic principles should simplify the interaction interface to reduce the user's cognitive load and enhance dynamic feedback, achieving immediate correction of movement deviations and risk warnings through the collaborative use of tactile, visual, and auditory multi-channel information. Intelligent safety braking technology can guarantee training intensity and reduce the risk of athletic injuries. With the breakthrough of flexible electronic technology and biosensors, rehabilitation equipment can capture subtle physiological signals more accurately, meet the needs of diverse rehabilitation scenarios, and further improve the rehabilitation effect.

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