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AHP-based Design of a Finger Training Device for Stroke

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***Abstract*—This study aims to develop a stroke finger training device specifically for office hand scenes which exercises the small muscles of the fingertips and improves the hand strength of stroke patients. The device has a real-time recording function for muscle strength changes during finger muscle training and enhances interaction through the feedback of training device data, thereby improving training effectiveness. This research involves analyzing hand postures and muscle movements in computer office scenes, designing questionnaires to obtain user requirements, and using the Delphi analysis method to screen key indicators and form standards and program layers. The Analytic Hierarchy Process (AHP) evaluates and ranks the core design elements. According to the design elements, the structure and training system design are guided, and a prototype is built for experimental testing. The results show that the training device effectively improves participants' hand strength, stability, and coordination and helps restore hand function. The AHP method allows for evaluating and ranking the device's design elements, making the device design more reasonable and comprehensive. Overall, the training device significantly improves the finger muscle strength of participants.**

Keywords—Stroke; rehabilitation training equipment; finger muscle strength; AHP; specific finger actions

I. INTRODUCTION

The incidence of stroke in China has been increasing yearly, and the number of young stroke patients has also increased in recent years [1-3]. Studies have shown that approximately 80% of stroke survivors experience finger dysfunction, especially abnormal finger muscle strength, which seriously affects their daily life and work ability [4,5]. Therefore, finger training has become a crucial part of rehabilitation treatment. Rehabilitation training usually requires rehabilitation equipment, as it can help patients restore joint mobility, increase muscle strength, improve finger coordination, relieve pain, prevent finger stiffness, and improve the quality of life [6].

However, research on existing patents, products, and literature shows that finger rehabilitation training equipment has the following characteristics.

From the perspective of device types, the significant classifications of hand rehabilitation training devices include exoskeletons and end-effectors, which include devices that encourage repetitive hand movements [7], peripheral sensory stimulation devices that promote sensory-motor control [8], and neuromuscular stimulation devices [9]. Based on the principle of neural reshaping [10], exoskeleton devices for finger rehabilitation simulate joint movements of the fingers or optimize materials to fit the hand joints better to promote movement of the affected limb and achieve neural reshaping for rehabilitation purposes.

For example, Luo Guangda et al. [11] designed a hand rehabilitation robot that optimizes its movement mechanism to simulate the movements of the distal interphalangeal joint, proximal interphalangeal joint and metacarpophalangeal joint, achieving finger flexion, extension and abduction. Wang Yangwei et al. [12] used shape memory alloy (SMA) filaments as actuators and adopted a soft glove structure for the hand exoskeleton, which has the advantages of good movement flexibility and high finger fit. End-effectors mainly focus on local hand movements to improve hand movement abilities. For instance, Fang Yufei et al. [13] proposed a hand finger rehabilitation device consisting of a base and a finger ring, which achieves finger flexion and extension through a long-pitched screw rotating inward, with a simple and compact structure, but limited in the direction of force, primarily simulating the force generation at the fingertips or distal phalanges towards the palms, which is seen in grasping actions, but not in other daily activities like picking, pinching, or tapping movements.

Regarding rehabilitation training objectives, the available devices can be divided into two categories: devices for strengthening the hands (using springs and other resistance equipment) and devices for training the range of motion of the fingers (using elastic rods and other devices). From the perspective of technological implementation, they can be further divided into virtual reality finger training devices (to enhance the training experience) and electric finger training devices (using sensing technology [14] and feedback [15] systems to help patients master movement techniques). From the perspective of design pathways, current rehabilitation training devices focus on optimizing drivers, controls [16], structures and trajectory lines [17-20].

While existing devices have played an essential role in the finger rehabilitation process, they lack specific muscle training for finger joint-specific movement positions (such as the particular movement involved in exerting force in a fixed direction at the fingertips in a working environment) and have limited ability to train the small muscles of each finger joint. For example, they mainly focus on overall finger extension and flexion [21], lacking individual finger and finger coordination training. Additionally, existing rehabilitation devices lack real-time feedback capabilities. Furthermore, young stroke patients who need to return to work require specific finger movements, which existing rehabilitation training devices lack. They cannot help patients transfer their practice skills to actual work, thus compromising the effectiveness of rehabilitation practice. Therefore, developing an effective finger training device is significant for stroke rehabilitation and can improve the patient's quality of life and rehabilitation effects.

This paper proposes the design of a stroke finger training device using the AHP method, which provides personalized movement training for specific hand movements and prepares young and middle-aged stroke patients to return to work. Firstly, we introduce the basic principles and steps of the AHP method. Then, based on scenario analysis and finger posture analysis, we obtain the finger training needs of stroke patients, determine the device's design requirements and functional modules, and evaluate and rank the importance of each functional module according to the AHP method, thereby determining the final design scheme.

To verify the feasibility of the design scheme, we built a testing prototype and developed testing software. In terms of hardware, we adopted a button training structure and used sensors and self-generated force to achieve finger strength, and coordination training. In terms of software, we developed a simple interactive application program that can adjust training difficulty, record and analyze data, and perform other functions.

Finally, we analyzed the test results, which showed that the device could effectively improve the people’s finger muscle strength. At the same time, the device has good adjustability and personalized features, which can be adjusted and optimized according to the needs of different patients, providing new ideas and methods for stroke finger rehabilitation training.

The main contributions of this paper are as follows:

1) From the perspective of industrial design, a rehabilitation training device that can record real-time finger force data is designed using the AHP method.

2) The paper proposes finger strength training for the distal finger joints of patients and emphasizes the importance of finger force exertion in work scenarios. The changes in muscle strength are used as parameters to evaluate the training progress.

II. RELATED WORK

A. Mechanisms of Hand Movement Training in Stroke Patients

Stroke can cause ischemia or bleeding in some brain regions, damaging motor pathways such as the corticospinal and pyramidal tract [22]. This damage can result in motor limitations and hand dysfunction [23]. Hand movement therapy primarily targets the damage caused by stroke to the motor pathways by promoting regeneration and reconstruction of these pathways and improving the patient's hand muscle strength, coordination, and fine motor skills [24].

Hand movement therapy includes active and passive movement training, such as hand stretching, grip exercises, and finger range of motion training. These exercises can be selected and combined based on the patient's specific needs to achieve the best rehabilitation results [25]. It is important to note that hand movement therapy is not suitable for all stroke patients, as different types and degrees of stroke can lead to various neurological damage and rehabilitation requirements [26]. Therefore, professional assessment and individualized rehabilitation plans need to be developed before conducting hand movement therapy, and the training process and intensity need to be quantified during the rehabilitation process.

B. The basic Principles and Steps of AHP

Analytic Hierarchy Process (AHP) was first proposed by American mathematician and decision scientist Thomas L. Saaty [27]. It is a multi-criteria decision-making method used to determine the relative importance of various factors in complex problems [28]. Its basic principle is to decompose the decision-making problem into multiple levels, from overall to detail, to determine the weight relationships between factors at each level and obtain the decision-making result. The specific steps are as follows:

Step 1: Determine the decision-making objectives and criteria. The various indicators at each level are obtained through questionnaires and the Delphi method.

The initial design elements were obtained by collecting 89 valid questionnaires. Five experienced rehabilitation physicians were invited as experts to determine the criteria and program design elements at the guideline and program layers. The Delphi method used in this study followed the rule of majority decision, with the consensus reached by the experts as the screening result for each round. The objective is denoted as O, the guideline layer as G, and the program layer as P.

Step 2: Construct the judgment matrix A_X. The scale type is 1-9[29, 30]. Experts are invited to construct the judgment matrix for each level element based on the scale type to evaluate the relative importance of each criterion.Xrefers to the judgment objects for constructing the judgment matrix A, such as the criteria-level G judgment matrix A_Gfor this research case, which can be represented as follows in the paper translation.

$$A_G = \begin{bmatrix} a_{11}(G1/G1) & \cdots & a_{11}(G1/G5) \\ \vdots & \ddots & \vdots \\ a_{11}(G5/G1) & \cdots & a_{ij}(G5/G5) \end{bmatrix} \tag{1}$$

i represents the row number of the matrix, and j represents the column number of the matrix.

Step 3: Calculate the weight vector W_i.

$$W_i = \sum_{i=1}^{n}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right) \tag{2}$$

n represents the order of the matrix.

Step 4: Consistency check.

$$CR = \frac{\lambda_{max}-n}{(\mathrm{n}-1)RI} < 0.1 \tag{3}$$

Calculate the maximum eigenvalue for each matrix

$$\lambda_{max} = \sum_{i=1}^{n}\frac{A_X*Wi}{nWi} \tag{4}$$

The matrix is considered acceptable when the consistency ratio CR is less than 0.1.

Step 5: Synthesize the total weight. The calculation method is the same as Formula (2).

In practical operations, the software can carry out the above calculation process. This study used a Matlab program for calculation.

C. Application of AHP to Product Design

AHP is a commonly used multi-criteria decision-making analysis method widely applied in many fields. In product design, Yang et al. [31] used AHP to analyze various aspects of design proposals for bathroom products. By analyzing different demand factors and determining their weights, the best solution can be obtained, and a bathroom product that meets user needs and balances various requirements such as aesthetics, economy, and environmental protection can be designed. Liu et al. [32] studied user behaviour workflows using the Symbolic Analysis Pathway Allotment Diagram (SAPAD), analyzed weights using AHP, and finally proposed a modified design plan for an intelligent charging station that meets users' needs. Wang et al. [33] used AHP to rank the design elements by weight and importance. They combined them with a fuzzy model to complete the packaging design of Baihua Honey agricultural products in Weixi County, Lijiang.

Therefore, AHP is a fundamental decision-making method that can be used independently or in combination with other methods to play a role in product design. In product design, AHP helps designers determine the optimal design solution and the weight of design elements, providing strong support for the design process.

III. MATH-HIERARCHICAL MODEL OF FINGER TRAINING NEEDS FOR YOUNG PEOPLE WITH STROKE

A. Situational Analysis

Computers are standard office equipment, and when patients manipulate the keyboard, their fingers need to perform combined movements of extension and flexion and exert force to hit the keys. Patients with high muscle tension may have difficulty extending their fingers, while those with muscle weakness may have difficulty exerting force, resulting in difficulty pressing the keys. Inflexible fingers can also reduce critical efficiency and cause mistakes, ultimately affecting work quality. Therefore, this study proposes the analysis of design requirements for training devices targeting the scenario of pressing the keyboard, as shown in Fig. 1.

B. Finger Posture and Muscle Analysis

According to the regularity of finger tapping on the keyboard, ignoring critical shortcut operations, only one finger taps the keyboard at a time. The fingers maintain a natural flexed state, with the tapping finger pressing down and the other fingers exerting an upward force to prevent mistakes. As shown in Fig. 2, two postures are maintained when tapping the keyboard, achieved through the cooperation of the finger extensor and flexor muscles. According to the anatomy of the fingers, the finger extensor muscles are located on the back of the fingers and mainly exert their effects through the extensor tendon cap, which is composed of the central tendon bundle and the lateral bundle, acting on the finger bones and exerting an extension effect. The finger flexor muscles inside the fingers achieve finger flexion. The four fingers are usually powered by the palm-to-finger joints, except for the thumb, passing through the proximal phalanx, middle phalanx, and ending at the distal phalanx tubercle. The thumb taps the keyboard less frequently and relies on the wrist and palm bones to reach the thumb tubercle. The force direction of the fingertips is perpendicular to the operating plane and downwards.

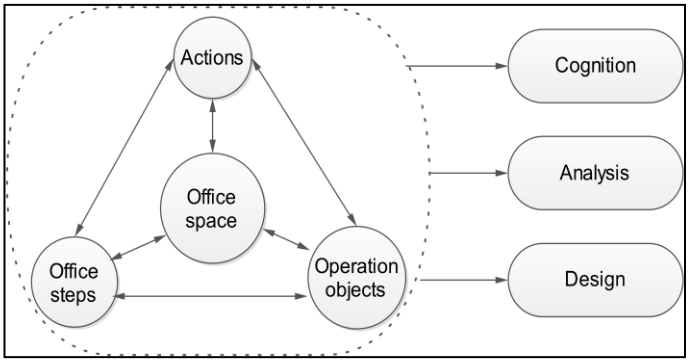

Fig. 1. Situation analysis chart.

C. AHP Hierarchical Model Construction

Based on the analysis of scenarios, finger posture, and muscle analysis, a questionnaire was designed for research, and primary indicators were obtained through cluster analysis. Rehabilitation therapists, equipment designers, and patients were invited to conduct indicator screening through the Delphi method. The indicator hierarchy was determined, and the final weights were calculated in Matlab according to the calculation principle of AHP in section 3.1, as shown in Fig. 3.

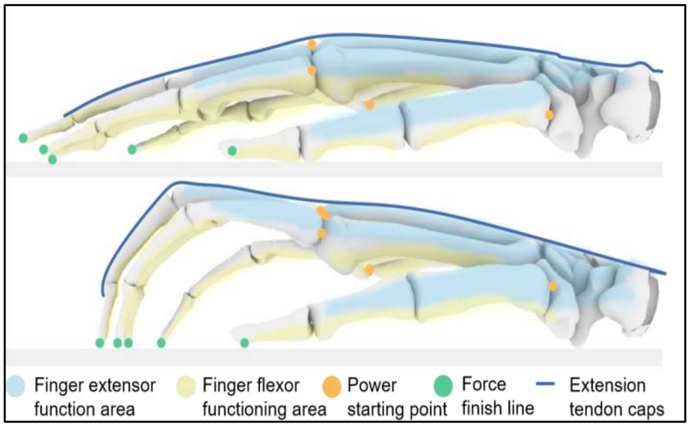

Fig. 2. Finger posture and muscle action areas.

IV. STROKE FINGER-TRAINING DEVICE DESIGN

According to the current overall ranking of the hierarchy, the main design elements need to be considered comprehensively in the quasi-side layer's corresponding elements and scheme layers. Based on this weight, the scheme's design can be carried out.

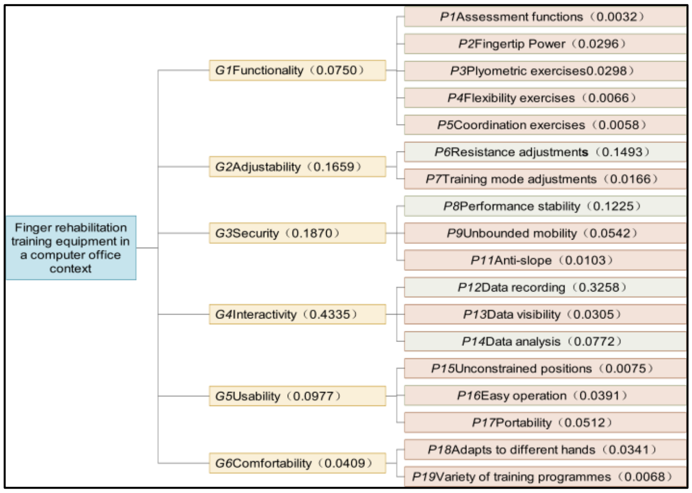

Fig. 3. Finger-training equipment design guidelines levels and weights.

A. Structural Design

Considering that finger force training requires a certain amount of resistance, and the force data and effective force frequency will serve as guiding parameters for finger muscle strength training, this study adopts PROE for modular design. The elements that make up the design of (a) keyboard structure is a pressing column, (b) spring limiting grooves, (c) enclosure, (d) spring, (e) retaining ring for the spring, (f) winding head, (g) coil, (h) force transducer, and (i) soldering point for the coil (see Fig. 4). The principle is to provide resistance to the small muscles of the hand through the compression of the spring by pressing the pressing column and to obtain finger force data through the force sensor. The electromagnetic induction principle of the current change produces the compelling force frequency.

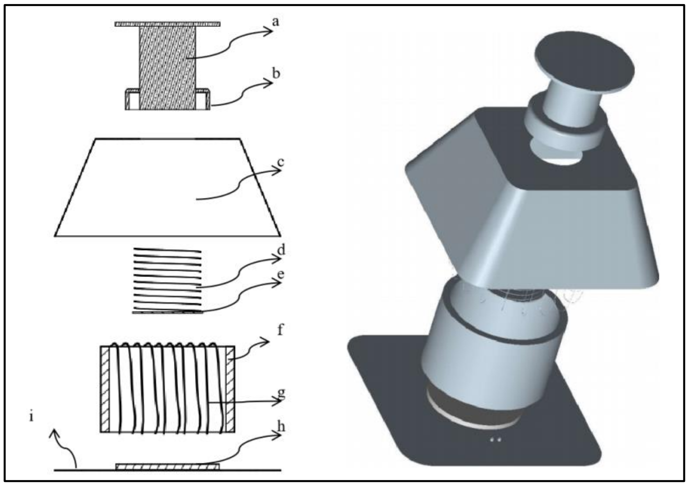

Fig. 4. Keypad construction parts, (a) pressing post, (b) spring limit slot, (c) housing, (d) spring, (e) spring retaining spacer, (f) winding post, (g) coil, (h) force sensor, (i) coil terminal.

Different springs can be replaced individually according to the muscle strength ability of different patients, gradually increasing or decreasing the spring elasticity to adapt to the needs of patients. The pressing column (a) and the spring limit threads connect the column slot. The bottom of the pressing column has magnetism. When the pressing column is pressed down, the spring contracts and the magnetic field lines of the magnet below the pressing column cut the coil, thereby affecting the direction of the coil current. The frequency of force is obtained by measuring the current's direction and number of changes. The spring and spring fixing gasket are fixedly connected to limit the spring from running and to facilitate the upper surface of the force sensor to contact fully, obtaining more accurate force measurement. Each keyboard structural component is connected to the controller and power supply through the wiring terminal, and the training results are displayed on the display screen through the data processor. The housing of the keyboard structural component allows the pressing column to pass through first and then fixes the spring limit slot with the pressing column bolt. It is fixed to the bottom surface of the keyboard by a buckle or adhesive, playing a role in dust-proofing and protection of the internal structure.

B. Training System Design

The training system consists of two parts: training programs and training operations. The relevant modules and logical relationships are shown in Fig. 5. Patients must first complete an assessment to determine whether they can actively move. According to the muscle strength grading standards established by the American Society of Rehabilitation Medicine (ASRM), the difference between grade 0 (no muscle activity) and grade 1 (slight muscle contraction but unable to move the joint) is muscle contraction. Therefore, a grade of 1 or higher indicates active movement.

During the test to determine whether the patient can actively move, data is collected when the patient presses the keyboard. The intelligent algorithm calculates the corresponding training program output and evaluation result based on the collected data. The initial data is used to assess whether the patient has muscle strength. Data analysis displays instructions and evaluation results on the screen to guide the patient in operating the keyboard. The intelligent algorithm is further optimized through repeated training and data accumulation iterations.

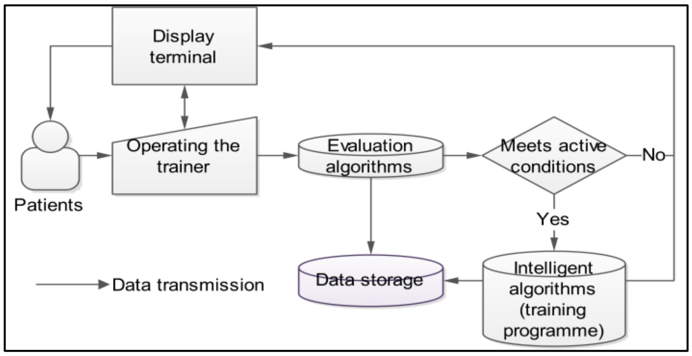

Fig. 5. Finger training system.

C. Training Methods

This training device is designed for finger strength and fingertip coordination training in a computer office setting. Compared to existing finger strength training devices, the training method in this study explicitly targets the finger force direction and coordination required in office scenarios. Previous research has shown evidence that standard keyboards can improve the fine motor skills of the fingers when typing [34, 35] and their coordination [36]. This training device adjusts the critical resistance and provides interactive feedback to facilitate finger movements. It allows patients to control their finger force, including the appropriate force activation of the keys, control of force direction, force magnitude, and speed. During the training process, patients are expected to exert force vertically on the keyboard surface to activate the muscles in their fingertips, thus achieving better rehabilitation outcomes.

The overall solution consists of a keyboard structure and display screen. The keyboard structure simulates the layout of a keyboard and can be configured for single or double-handed operation, allowing for single and double-handed training. Depending on the patient's level of disability, either a single or double keyboard may be used. The single keyboard primarily focuses on training individual letters, emphasizing muscle strength training. In contrast, the double keyboard focuses on meaningful word or sentence combinations, emphasizing finger coordination training. Since both keyboards are interchangeable, the program must be configured to recognize which hand, left or right, is associated with the selected keyboard. The keyboard and screen interface uses a standard USB interface. The display screen can be a regular monitor or touchscreen, as shown in Fig. 6.

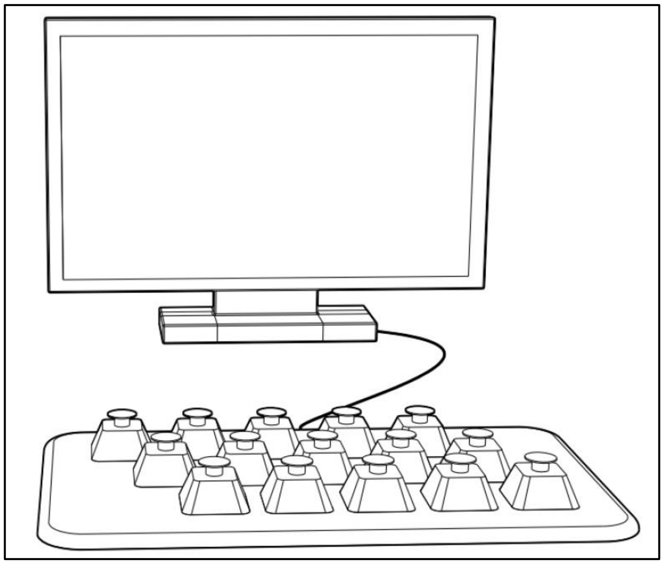

Fig. 6. One-handed training configuration illustration.

During training, posture is essential. Patients are instructed to adjust to a comfortable sitting position and relax their hand posture. Fingers should be placed on the training keyboard, and precise finger movement is achieved by tapping the keyboard with fingertips or finger pads. During single-handed training, the system configures the corresponding keyboard letters for the affected hand based on on-screen prompts. The typical keyboard letters and positions are displayed on the screen, and the patient operates the keyboard after observing the prompts. Data is recorded on the finger force and the frequency of force variation on a single key (quantified by the number of electrical current changes during crucial press). During double-handed training, the double keyboard is selected, and the screen interface is chosen for the corresponding hand's keyboard to avoid incorrect keyboard settings. The pre-set words, phrases, or sentences are then used for keyboard operation, with the completion time recorded as a basis for later evaluation.

V. TESTS AND RESULTS

A prototype device and system have been developed, as shown in Fig. 7, to validate finger muscle strength and coordination. In addition to the designed structure of this research project, the hardware includes the FSR402 thin film pressure sensor and pressure sensing module. The upper computer is compiled using VC++ 6.0.

A total of 30 participants were recruited for this study, with ages ranging from 22 to 40 years old. All other participants were in good physical health except for one stroke patient. Due to the difficulty in finding stroke patients as participants, this study did not compare stroke patients with healthy participants. Instead, the study assumed that the device would have training effects on healthy individuals and be effective for stroke patients.

The participants were divided into two groups: Group 1 consisted of 15 participants who underwent single-handed training and testing (using their non-dominant hand). In contrast, Group 2 consisted of 15 participants who underwent dual-handed training and testing.

There was no separate control group in this study. The initial test values for each group were used as the control, and the program's feasibility was analyzed by comparing the data before and after training. For single-handed training, the letters "A, S, D, F" were pressed 20 times; for double-handed training, the phrase "WOAIWODEZUGUOZ" was pressed 20 times. Muscle strength increase was measured for the single-handed training, and hand coordination was measured for the double-handed training. Since data was collected in real-time, the final data was determined based on the last test results obtained for each finger after training completion. The test results are presented in Table I, Fig. 8, and Fig. 9.

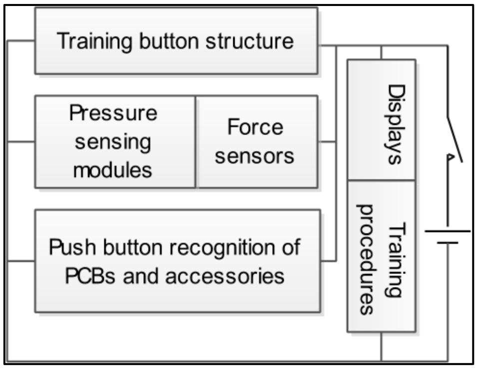

Fig. 7. Prototype schematic diagram.

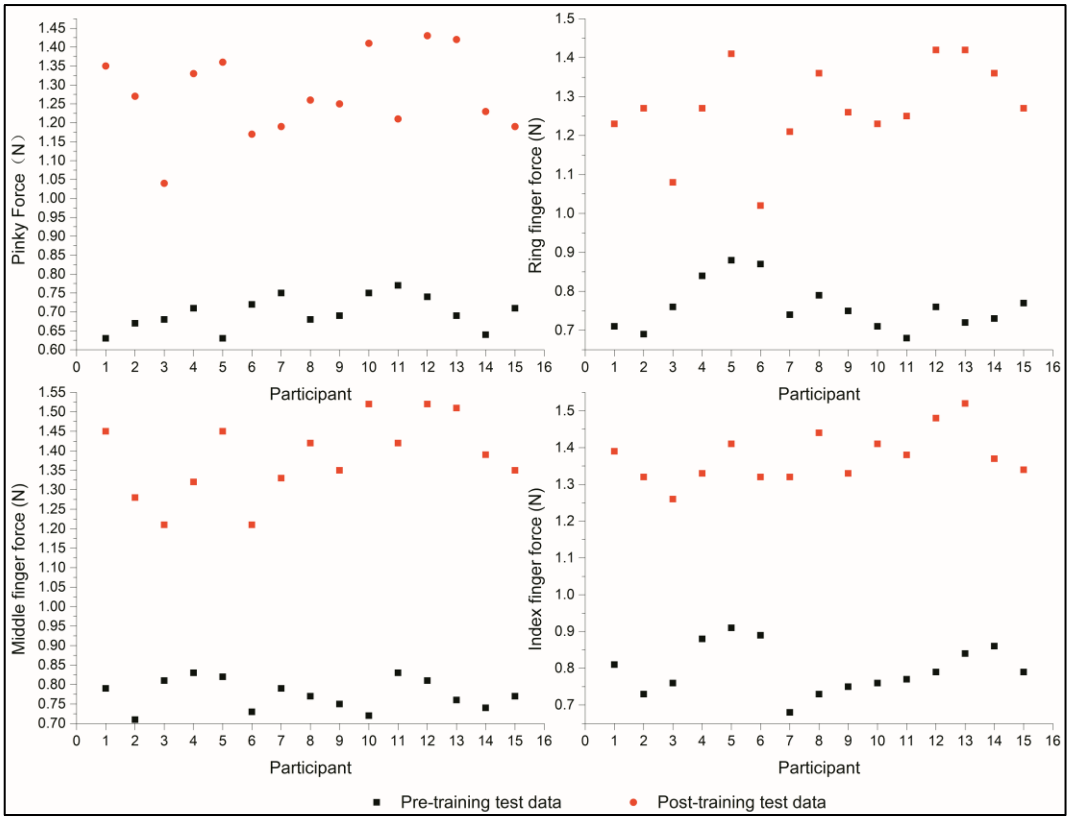

Fig. 8. Comparison of fingertip strength before and after one hand training.

TABLE I. ONE-HANDED TRAINING OF MUSCLE STRENGTH CHANGES AND FREQUENCY OF FORCE CHANGES

CATEGORIES		**MUSCLE POWER (N)**				**FREQUENCIES**
		Min	Max	Mean	SD	Mean
PRE-TRAINING	Pinky Finger	0.63	0.77	0.70	0.04	4.33
	Ring Finger	0.68	0.88	0.76	0.06	3.87
	Middle finger	0.71	0.83	0.78	0.04	2.73
	Index finger	0.68	0.91	0.80	0.07	2.60
POST-TRAINING	Pinky Finger	1.04	1.43	1.27	0.11	1.67
	Ring Finger	1.02	1.42	1.27	0.12	1.07
	Middle finger	1.21	1.52	1.38	0.10	1.07
	Index finger	1.26	1.52	1.37	0.07	1.00

VI. DISCUSSION

Based on the test data, Group 1 subjects showed varying degrees of increases in finger muscle strength after training, as shown in Fig. 8 and Table I: the force of the little finger increased from 0.70±0.04 (N) to 1.27±0.01 (N), the force of the ring finger increased from 0.76±0.06 (N) to 1.27±0.12 (N), the force of the middle finger increased from 0.78±0.04 (N) to 1.38±0.10 (N), and the force of the index finger increased from 0.80±0.07 (N) to 1.37±0.07 (N); the frequency of force change decreased, and the mean range of changes before training of [2.6, 4.33] changed to [1, 1.67], indicating more stable force production. In Group 2, the training completion time decreased from 35.3±4.25 (S) before to 23.7±5.32 (S) after training, indicating improved finger coordination. The experimental results indicate that the stroke finger training device based on AHP can effectively improve stroke patients' recovery of finger function and coordination ability. During the training process, the finger muscle strength of the subjects was significantly improved, and the stability of force production and coordination ability was significantly improved.

The objective of this study is to increase finger muscle strength and control in stroke patients through the use of an active training device. However, there are certain limitations for patients using this device. Firstly, patients need to be able to extend their fingers and push individual fingers downward. Secondly, they need to increase the strength of their finger flexor muscles.

In this experiment, muscle strength testing is measured by the force exerted when pressing keyboard keys with the fingers. Based on general knowledge, humans tend to exert the minimum or moderate force necessary to achieve the desired movement. However, stroke patients with weaker finger muscles need to increase their finger muscle strength and improve their control over movements. Compared to the average peak force of 0.86N generated by healthy individuals pressing standard spring-column keyboards [37], this training device can generate a range of crucial contact forces, including 0.86N. Through training, patients' finger muscle strength gradually increases. Healthy individuals typically exert the minimum force necessary to control their movements while pressing keys. However, to exercise the finger muscles of stroke patients, the spring resistance of the training device needs to be adjusted to accommodate the requirements of finger muscle training and enhance muscle strength.

However, increasing finger muscle strength training does not mean continuously increasing muscle strength. The goal is to exercise finger control so patients can perform finger-pressing operations required in office tasks. Therefore, this device adjusts the spring resistance for muscle strength training and protection. Whether further muscle strength training is needed depends on the muscle strength assessment conducted by the rehabilitation therapist.

This approach uses changes in muscle strength as an indicator, as individual muscle strength values do not fully represent the practical significance of rehabilitation muscle strength. The change in muscle strength value serves only as a reference for whether muscle strength gradually increases, combined with a reduction in task completion time to demonstrate the improvement in finger control ability after muscle strength training. The change in muscle strength value is not optimal for rehabilitation indicators, so this study did not consider the resolution of force change sensitivity. Choosing 20 training and testing key presses is not a standard for rehabilitation training frequency. This number is set to allow participants to become accustomed to the operation and reduce possible testing errors. The frequency should be set in actual training based on the patient's willingness and finger muscle condition.

In summary, this study aims to increase finger muscle strength and control in stroke patients through an active training device and to evaluate the training effects through changes in muscle strength and task completion time.

Compared with traditional devices [11-13], the main advantage of this rehabilitation training device is that it meets the exercise needs of finger operation on a computer through the keyboard structure in combination with a display screen and corresponding program settings, with active training being the focus. The device has several features: (1) it allows for free selection of single or double-handed training, and difficulty can be gradually increased based on the patient's finger movement deficiencies to improve both muscle strength and flexibility; (2) it can collect data in real-time, facilitating adjustments to the training program and evaluation of rehabilitation progress; (3) it has wide adaptability and can accommodate different finger sizes, without restrictions on the middle or distal finger joints, allowing patients more freedom to adjust their own posture; (4) costs are reduced, as the device can be modified based on existing keyboards, being highly feasible, and the keyboard operation is a familiar operation, which is easy for the patient to understand and learn, making it easy to promote; (5) it can be used in both hospital and home settings, without being limited by the application environment, and by using the AHP method to evaluate and rank the importance of each design element, overlooked design points can be discovered. The experimental results show that this finger training device significantly improves the recovery of finger function in stroke patients and has advantages such as ease of use and practicality.

The research method of this article is based on the AHP method, which evaluates and ranks the importance of each design element to make the device design more reasonable and adequate. This method can provide a new idea and method for designing other similar rehabilitation devices to improve their application effectiveness and practicality.

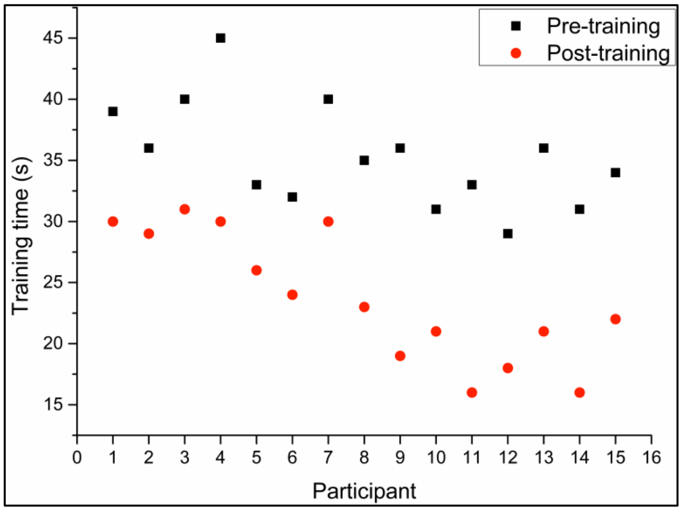

Fig. 9. Comparison of the time taken to complete a session before and after two-handed training.

VII. CONCLUSION

Through the research in this paper, we have successfully designed a stroke finger training device based on AHP. It can meet the exercise needs of finger operation on a computer, with active training being the focus. By using the AHP method to evaluate and rank the importance of each design element, overlooked design points can be discovered. The experimental results show that this finger training device significantly improves the recovery of finger function in participants and has advantages such as ease of use and practicality.

However, some things could be improved in this study. For example, the sample collection for the experiment mainly consisted of healthy subjects. In future clinical studies, it would be necessary to include more stroke patients as subjects to improve the reliability and persuasiveness of the experimental data. Additionally, the control module of the device can be further improved to enhance its intelligence and user experience. Future research can further explore this training device's application scope and effectiveness and combine it with other rehabilitation treatments to improve the rehabilitation outcomes for stroke patients. Furthermore, the design and functionality of the device can be further improved and refined to meet the needs of patients with different rehabilitation requirements.

REFERENCES

[1] X. Zhao, H. Chen, X. Dong, Q. Zou, X. Liang, J. Wu, and C. Wang, "Trends in stroke incidence in Nanshan district from 2010 to 2021," Preventive Medicine, vol. 35, no. 3, pp. 200-204, 2023, doi: 10.19485/j.cnki.issn2096-5087.2023.03.004.

[2] R. Zhang, W. Ji, L. Han, and L. Zhang, "Trends in incidence and mortality of stroke in Ningbo City from 2012 to 2021," Preventive Medicine, vol. 35, no. 3, pp. 224-228, 2023, doi: 10.19485/j.cnki.issn2096-5087.2023.03.009.

[3] W. Zhang, X. Qin, W. Li, Z. Ma, and J. Dong, "Analysis of the trends in the incidence of stroke in Lianyungang City from 2014 to 2020," Preventive Medicine, vol. 34, no. 9, pp. 932-936, 2022, doi: 10.19485/j.cnki.issn2096-5087.2022.09.014.

[4] T.J. Liang, "Research progress on rehabilitation treatment of upper limb dysfunction in stroke hemiplegia," Journal of Guangxi Medical University, vol. 35, no. 7, pp. 1026-1030, Jul. 2018. doi: 10.16190/j.cnki.45-1211/r.2018.07.03.

[5] P. Polygerinos, S. Lyne, Z. Wang, et al., "Towards a soft pneumatic glove for hand rehabilitation," 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems, Tokyo, Japan, 2013, pp. 1512-1517, doi: 10.1109/IROS.2013.6696549.

[6] H.J. Wu, L.N. Wu, L. Li, et al., "Research Progress of Comprehensive Intervention of Hand Function Rehabilitation Robot for Stroke," Journal of Biomedical Engineering, vol. 36, no. 1, pp. 151-157, Feb. 2019, doi: 10.7507/1001-5515.201711024.

[7] N. Friedman, V. Chan, A. N. Reinkensmeyer, et al., "Retraining and assessing hand movement after stroke using the MusicGlove: comparison with conventional hand therapy and isometric grip training," Journal of neuroengineering and rehabilitation, vol. 11, pp. 76, Apr. 2014, doi:10.1186/1743-0003-11-76.

[8] N.J. Seo, M.L. Woodbury, L. Bonilha, et al. "TheraBracelet Stimulation During Task-Practice Therapy to Improve Upper Extremity Function After Stroke: A Pilot Randomized Controlled Study," Physical therapy, vol. 99, no. 3, pp. 319-328, 2019, doi: 10.1093/ptj/pzy143.

[9] R. G. Barelli, V. F. Avelino, and M. C. F. Castro, "STIMGRASP: A Home-Based Functional Electrical Stimulator for Grasp Restoration in Daily Activities," Sensors (Basel), vol. 23, no. 1, pp. 10, Dec. 2022, doi: 10.3390/s23010010.

[10] R. M. W. de Oliveira, "Neuroplasticity," Journal of Chemical Neuroanatomy, vol. 108, pp. 101822, 2020, doi: 10.1016/j.jchemneu.2019.101822.

[11] G. D. Lu, Q. Y. Zhang, N. An, et al., "Kinematic simulation analysis of hand rehabilitation robot based on ADAMS," Machine Design, vol. 37, no. 6, pp. 87-90, 2020.

[12] Y. W. Wang, P. L. Lu, S. F. Zheng, et al., "Design of a shape memory alloy-driven functional finger rehabilitation exoskeleton," Journal of Zhejiang University (Engineering Edition), vol. 54, no. 12, pp. 2340-2348, 2022, doi: 10.3785/j.issn.1008-973X.2022.12.015.

[13] Y. F. Fang and X. Guo, "A finger rehabilitation training device," Patent number CN 210197649 U, Dec. 2020.

[14] Y. L. Xie, Y. X. Yang, H. Jiang, et al., "Brain-machine interface-based training for improving upper extremity function after stroke: A meta-analysis of randomized controlled trials," Frontiers in Neuroscience, vol. 16, pp. 949575, 2022, doi: 10.3389/fnins.2022.949575.

[15] S. Feng, M. Tang, G. Huang, et al., "EMG biofeedback combined with rehabilitation training may be the best physical therapy for improving upper limb motor function and relieving pain in patients with the post-stroke shoulder-hand syndrome: A Bayesian network meta-analysis," Frontiers in Neurology, vol. 13, pp. 1056156, 2023, doi: 10.3389/fneur.2022.1056156.

[16] H. B. Wang, B. Yan, X. C. Wang, et al., "Design of end-traction finger rehabilitation robot and its flexibility control method," China Science and Technology Paper, vol. 15, no. 7, pp. 743-749, 2020.

[17] M. Li, J. Z. Chen, B. He, et al., "Motion planning and structural optimization of a multi-segment continuous structure hand functional rehabilitation exoskeleton," Journal of Xi'an Jiaotong University, vol. 53, no. 10, pp. 1-11, 2019.

[18] M. W. Zhong, Y. F. Feng, Z. M. Chen, et al., "Structural design and control system design of a progressive finger rehabilitation robot," Mechanical Design, vol. 39, no. 10, pp. 27-33, 2022.

[19] A. Abbasi Moshaii, M. Mohammadi Moghaddam, and V. Dehghan Niestanak, "Fuzzy sliding mode control of a wearable rehabilitation robot for wrist and finger," Industrial Robot: The International Journal of Robotics Research and Application, vol. 46, no. 6, pp. 839-850, 2019, doi: 10.1108/IR-05-2019-0118.

[20] X. Zhang, X. Mo, C. Li, et al., "A wearable master-slave rehabilitation robot based on an epidermal array electrode sleeve and multichannel electromyography network," Advanced Intelligent Systems, vol. 5, no. 3, pp. 2200313, 2023, doi: 10.1002/aisy.202200313.

[21] S. F. M. Toh, P. F. Chia, and K. N. K. Fong, "Effectiveness of home-based upper limb rehabilitation in stroke survivors: A systematic review and meta-analysis," Frontiers in Neurology, vol. 13, pp. 964196, 2022, doi: 10.3389/fneur.2022.964196.

[22] P. Langhorne, F. Coupar, and A. Pollock, "Motor recovery after stroke: A systematic review," The Lancet Neurology, vol. 8, no. 8, pp. 741-754, 2009, doi: 10.1016/S1474-4422(09)70150-4.

[23] S. H. Cauraugh and R. W. Summers, "Upper extremity rehabilitation in stroke: The importance of understanding motor control," Neurology Report, vol. 25, no. 2, pp. 55-60, 2001, doi: 10.1097/01253086-200125020-00003.

[24] J. H. Broeks, J. Lankhorst, and G. Rumping, "The long-term outcome of arm function after stroke: Results of a follow-up study," Disability and Rehabilitation, vol. 22, no. 6, pp. 261-264, 2000, doi: 10.1080/096382800406431.

[25] R. W. Bohannon, "Hand-grip dynamometry predicts future outcomes in aging adults," The Journal of Geriatric Physical Therapy, vol. 33, no. 1, pp. 3-10, 2010, doi: 10.1519/JPT.0b013e3181ceaa5a.

[26] M. M. Shaughnessy, P. A. Michael, and C. A. Siders, "Upper-extremity function and recovery in the acute phase poststroke," Journal of Neurologic Physical Therapy, vol. 28, no. 3, pp. 157-166, 2004, doi: 10.1097/01.NPT.0000140644.95819.4F.

[27] T. L. Saaty, "How to make a decision: The analytic hierarchy process," European Journal of Operational Research, vol. 48, no. 1, pp. 9-26, 1990, doi: 10.1016/0377-2217(90)90057-I.

[28] L. Xu and X. Chen, "A review of multi-criteria decision-making methods based on the analytic hierarchy process," International Journal of Information Technology & Decision Making, vol. 11, no. 02, pp. 445-472, 2012, doi: 10.1142/S021962201240006X.

[29] T. L. Saaty, "Fundamentals of decision making and priority theory with the analytic hierarchy process," RWS Publications, Pittsburgh, PA, USA, 2000.

[30] W. W. Chin, "The partial least squares approach to structural equation modeling," in Modern Methods for Business Research, G. A. Marcoulides, Ed. Mahwah, NJ: Lawrence Erlbaum Associates, 1998, pp. 295-336.

[31] X. Yang and Z. Zhang, "Design of bathroom products based on AHP hierarchical analysis method," Packaging Engineering, vol. 42, no. 4, pp. 144-147+153, 2021, doi: 10.19554/j.cnki.1001-3563.2021.04.019.

[32] Z. Liu and Z. Wang, "Research on intelligent charging pile design based on SAPAD-AHP method," Journal of Graphics, vol. 44, no. 2, pp. 380-388, 2023.

[33] Z. Wang and J. Xu, "Design and evaluation of agricultural special product packaging based on AHP and fuzzy model," Packaging Engineering, vol. 43, no. 6, pp. 213-219, 2022, doi: 10.19554/j.cnki.1001-3563.2022.06.028.

[34] A. Schlenker and T. Tichý, "A new approach to the evaluation of local muscular load while typing on a keyboard," Central European Journal of Public Health, vol. 25, no. 4, pp. 255-260, 2017, doi: 10.21101/cejph.a4824.

[35] M. L. Chang and C.-H. Shih, "Improving fine motor activities of people with disabilities by using the response-stimulation strategy with a standard keyboard," Research in Developmental Disabilities, vol. 35, no. 8, pp. 1863–1867, 2014. doi: 10.1016/j.ridd.2014.04.011.

[36] J. F. Soechting and M. Flanders, "Flexibility and repeatability of finger movements during typing: Analysis of multiple degrees of freedom," Journal of Computational Neuroscience, vol. 4, no. 1, pp. 29-46, 1997, doi: 10.1023/A:1008877207867.

[37] M. J. Bufton, R. W. Marklin, M. L. Nagurka, and G. G. Simoneau, "Effect of keyswitch design of desktop and notebook keyboards related to key stiffness and typing force," Ergonomics, vol. 49, no. 10, pp. 996-1012, 2006, doi: 10.1080/00140130600577437.