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Clinical Analysis of Five-month Neurological Function Rehabilitation in Stroke Patients with Hemiplegia

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Abstract: Stroke is a common and multiple acute cerebrovascular disease in clinical practice, with high morbidity, high disability rate and high mortality rate. According to statistics, the incidence of stroke is about 0.2%, of which 75% of patients would develop hemiplegia. This article takes stroke patients with hemiplegia as the research object to explore the effect of rehabilitation training within five months. In the analysis of the algorithm applied to the exoskeleton robot, the interaction force between the human leg and the exoskeleton is maintained at a level of 45N to 65N, with a maximum of 64N, without actively participating in the rehabilitation training. The interaction force between the leg and the exoskeleton is maintained at a level of 23 N to 35 N, with a maximum of 35 N. After active participation in rehabilitation training, the interaction force between the legs and the exoskeleton increased significantly, reaching 27 N to 39 N, with a maximum of 39 N. Therefore, it is very necessary to use exoskeleton robots for rehabilitation training.

1. Introduction

Hemiplegia is a condition where engine capability on one side of the body is weakened because of mind harm. Any condition that damages the brain can lead to paralysis, the most common being hemiplegia due to stroke. With the increasingly prominent problem of population aging, more and more stroke patients are caused by stroke. How to improve their autonomous activities, improve their quality of life, and use mechanical devices to assist patients in hemiplegic rehabilitation training, so that they can break away from the shackles of manual training, has become very important. The first is to artificially control the patient to stand and walk, which is actually to stand and balance the patient's lower limbs. In rehabilitation training, how to overcome the defect of pure passive posture control and better allow patients to better participate in rehabilitation training is an urgent problem that needs to be solved. In this paper, a speed-based auxiliary algorithm is used to carry out gait rehabilitation training for stroke patients, so that the patients can independently participate in the rehabilitation training and actively exert the motor function of the unaffected side, thereby preventing the injury of the healthy side, which has high economic and social benefits.

The clinical analysis of neurological rehabilitation in stroke patients is a hot topic in current research, among which: The purpose of Shuhei I was to examine the effect of lower extremity exercise on neurological rehabilitation in hemiplegic stroke patients [1]. Uwatoko H suggested that since free step is a significant calculate home release, early expectation of autonomous walk after stroke is urgent [2]. The purpose of Ha S Y was to study the effect of Fresnel prism glasses on balance and gait in stroke patients with hemiplegia, including 17 stroke patients with hemiplegia without unilateral neglect [3]. Dehno N S was designed to evaluate the feasibility of using isokinetic dynamometric methods to assess carpal flexor spasticity in stroke patients [4]. The purpose of Kim C Y's study was to compare the effects of backward and lateral walking training and to determine whether additional backward or lateral walking training would be more effective in increasing walking function in post-stroke patients [5]. However, the above studies are due to insufficient data sources. As a result, the research is only in the theoretical stage and has no practicality.

The use of computer technology is very important for the clinical analysis of the rehabilitation of stroke patients, among which: The trial by Tomida K aimed to verify the effectiveness of using a gait motion-assisted robot in patients with primary post-stroke hemiplegia [6]. The purpose of Wei N N is to explore the effect of balance acupuncture combined with exercise relearning training on the motor function of lower limbs in stroke patients with hemiplegia [7]. Yong I S proposed that bioelectrical impedance analysis is widely used to evaluate whole body fat content and sometimes visceral fat content to evaluate the rehabilitation effect of stroke patients [8]. Min C C evaluated the effect of short-ankle-foot orthoses in post-stroke hemiplegia patients by comparing the effects of short-ankle-foot orthoses with traditional solid plastic [9]. The purpose of Misato M was to explore the characteristics of retrograde walking in hemiplegic patients with stroke from the aspects of joint motion and torque, walking speed, stride, and cadence on the hemiplegic side [10]. However, due to the traditional thinking and definition, the above research cannot achieve a high degree of integration and give play to their advantages.

The main work of this paper is as follows: (1) An auxiliary algorithm based on self-adaptation—a speed-based auxiliary algorithm, which can help patients perform rehabilitation training in different rehabilitation states, and allow patients to actively participate in rehabilitation training. (2) According to the different recovery states and different movement rates of the patients, the speed of the exoskeleton is adopted to minimize the interaction between the patient and the exoskeleton.

2. Neurological Rehabilitation of Stroke Patients

2.1. Overview of Stroke

According to the definition of the World Health Organization (WHO), stroke, also known as cerebrovascular accident, is mainly caused by the sudden rupture of blood vessels or blockage of blood clots, resulting in the obstruction of blood circulation in the brain, and resulting in the lack of oxygen and the supply of nutrients. According to the "2018 China Health Statistics Summary", there are currently 12.42 million stroke patients aged 40 and above in China, and 1.96 million patients die every year nationwide [11-12]. Stroke can lead to a variety of physiological disorders. The reason is the difference in the location, nature and scope of brain damage.

In stroke, the most common is dyskinesia. The upper limbs and hands perform many fine and complex movements, but because the non-crossed muscles of the upper limbs are less than those of the lower limbs, it is difficult to restore the motor function of the upper limbs. The results show that even after rehabilitation training, 30% to 66% of patients still develop limb dysfunction after 6 months, and only 5 to 20% of patients can fully recover. Research data show that 1 year after a stroke, loss of upper extremity function can lead to higher levels of anxiety, lower health awareness, and lower happiness. In addition, stroke rehabilitation nursing workers would also suffer from mental and psychological pressure for a long time, and would reduce the quality of life. Most stroke patients are disabled for a long time, which would also bring great impact on society and economy. Accordingly, the recuperation of upper appendage engine capability for stroke patients is the concentration and trouble of recovery treatment. Dynamic early restoration is a significant piece of current stroke recovery to lessen the inability pace of stroke and further develop the endurance pace of patients.

(1) Rehabilitation treatment of upper limb motor function of hemiplegia after stroke

A large number of trials have confirmed that rehabilitation training can significantly promote the recovery of upper limb motor function in stroke patients by performing high-intensity training for specific tasks in an active, functional, and highly repetitive manner.

(2) Brunnstrom Therapy

Braunstrom therapy was proposed by a Swedish physiotherapist, who divided the movement pattern after stroke into six stages: 1st stage - relaxation stage, 2nd stage - spastic stage, 3rd stage - coordinated movement stage, 4th stage - partially dissociated active stage, 5th stage - dissociated active stage, sixth stage - normal. It believes that after the central nervous system injury, the process of its recovery is a dynamic change, that is, after experiencing the joint response-co-action, the separation movement begins [14-15]. Therefore, Brunstron therapy advocates the use of a strong combined response.

2.2 Systematic Introduction of Rehabilitation Therapy

(1) Overview of Hemiplegia Rehabilitation System

In this paper, the exoskeleton system for hemiplegia rehabilitation is designed in detail, and the corresponding action modules and control logic are given. The system is designed according to the bionic structure and can carry out data acquisition. Since the system has several motion modes, the "Assist by Speed" mode described in this article is one of them. On this basis, this paper locates the exoskeleton of hemiplegic patients and designs a pressure sensor module for interaction. Hemiplegia rehabilitation exoskeletons are used to perform daily activities such as standing, walking, sitting, etc.

The mechanical structure, which draws on the design of the bionic man, is connected with the exoskeleton to form a complete whole. In order to accurately measure the angle of joints and other movements, the user must be tightly attached to the exoskeleton by binding [16-17]. The main content of the software is to establish a visual control panel, and use the communication protocol to realize data exchange and control the motor.

(2) Software system framework

The exoskeleton software system can be divided into application layer, data layer, transport layer and physical layer in total. The application layer is mainly responsible for the control of the exoskeleton, the functions of multiple modules such as getting up, sitting, and walking, while the transport layer includes the controller area network (CAN) bus communication protocol and the corresponding driver modules. The application layer data is converted into electrical signals by the data layer, and then transmitted by the physical layer to the transport layer, and finally transmitted by the transport layer to other nodes, thus completing the overall control of the entire system. In addition, it also transmits the signals of each node to the main control board. The physical layer is mainly composed of the physical connection between the main control board and the main node, as shown in Figure 1:

Figure 1. Exoskeleton software system framework

Figure 1 shows the structure of the exoskeleton software system. The application layer adopts the method of task division, and divides the main control software into human-computer interaction, gait planning, joint information feedback, human-computer interaction, fall alarm and finite state machine. During initialization, it sets the time interval for each task, and then uses a timer to calculate it. When tasks are completed, they are placed in the task queue in order of priority. During idle time, the master would search for the task with the highest priority in the task queue. After execution, delete it and then go to find the next most important task.

2.3 Gait Mapping Algorithm Based On Dynamic Motion Primitives

The most common clinical neurological dysfunction is abnormal gait. In hemiplegic patients, due to increased abductor muscle group and lower limb extensor muscle tension, the knee joint cannot be coordinated and elongated, and the ankle and foot drop, so that the affected limb is relatively elongated. The gait is characterized by slight up-and-down, vigorous side-to-side movements, stiffness of the knees and hips, and a pronounced circular gait that appears in the form of uncoordinated movements. Moreover, other parts of the patient's body would also slowly recover. Over time, the patient's attention would be excessively focused on the unaffected side, resulting in osteochondrosis on the unaffected side. Therefore, for hemiplegic patients with movement disorders on one side, in order to improve their limb function, they must adopt an appropriate gait. In the rehabilitation of hemiplegia, although most of the algorithms are carried out according to the trajectory of normal people. But because everyone is different in height, pace, and timing of activity, using a fixed reference track isn't fully adaptable to stroke recovery. Its overall frame is shown in Figure 2.

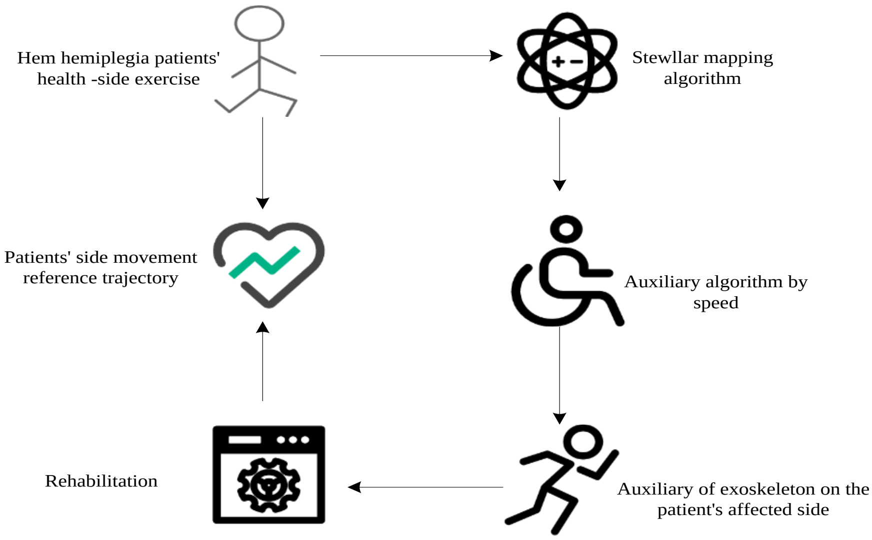


Figure 2. Rehabilitation training flow chart

In this paper, the dynamic motion primitive (DMP) can be used to construct the gait trajectory, and the gait trajectory can be represented according to the joint angle data of the hip and knee joints. The joint angle modeling method is as follows:

$$\lambda^2 \ddot{\theta} = a(\beta(\theta_g - \theta) - \lambda \dot{\theta}) + P(f - x(\theta_g - \theta_0)) \tag{1}$$

Among them, $\theta, \dot{\theta}$ and $\ddot{\theta}$ represent the joint angle, joint angular velocity and joint angular acceleration, respectively. λ represents a constant, θ_0 and θ_g are the initial and target angles of the joint, respectively. α , β and P are all constants.

$$P = a\beta \tag{2}$$

$$f(x) = \frac{\sum_{i=1}^{N} \phi_i(x) w_i x}{\phi_i(x)} \tag{3}$$

Through the dynamic motion primitives, the motion trajectory of the unpowered leg of the exoskeleton robot, that is, the motion trajectory of the patient's unaffected side, can be used to generate the reference trajectory of the patient's affected side motion, and apply it to the speed-based assistance algorithm. In order to verify the effectiveness of the DMP algorithm, this paper also designs the PVT interpolation algorithm for comparison.

The patient's own strength is unlikely to affect the movement of the exoskeleton. Therefore, before rehabilitation training, the moment of the hip and knee joints must be calculated by the gravity of the exoskeleton, and then the exoskeleton is used to make it easier for the patient to carry out rehabilitation training. First, model the dynamic equations:

$$M(\theta)\ddot{\theta} + C(\theta, \ddot{\theta}) + G(\theta) = \tau_{com} \tag{4}$$

Among them: $\theta = [\theta_{hh} \quad \theta_h]^T$, which represents the hip and knee angle, M represents the mass matrix, C represents the Coriolis force, centrifugal force moment, and G is a gravitational matrix. $\tau_{com} = [\tau_1 \quad \tau_2]$ represents the compensating moment applied to the hip and knee joints. So the kinetic energy of the thigh is:

$$T_1 = \frac{1}{2} I_A \theta_1^2 \tag{5}$$

Among them, I_A is the moment of inertia of the thigh, θ_1^2 is the instantaneous velocity of the hip joint, and the kinetic energy of the calf is:

$$K_2 = \frac{1}{2} I_D (\dot{\theta}_1 + \dot{\theta}_2) + \frac{1}{2} m_2 V_D^2 \tag{6}$$

Among them, I_D is the moment of inertia of the calf, θ_2^2 is the instantaneous speed of the knee joint, and the total kinetic energy of the system is obtained:

$$T = T_1 + T_2 \tag{7}$$

The total potential energy of the system is:

$$P = \frac{1}{2} m_1 g l_1 \sin\theta_1 + m_2 g (l_1 \sin\theta_1 \ + \frac{1}{2} l_2 \sin(\theta_1 + \theta_2)) \tag{8}$$

Through the Lagrangian function and the kinetic equation:

$$L = T - P \tag{9}$$

$$\tau_1 = \frac{\partial}{\partial t} * \frac{\partial L}{\partial \dot{\theta}_1} - \frac{\partial L}{\partial \theta_1} \tag{10}$$

$$\tau_2 = \frac{\partial}{\partial t} * \frac{\partial L}{\partial \dot{\theta}_2} - \frac{\partial L}{\partial \theta_2} \tag{11}$$

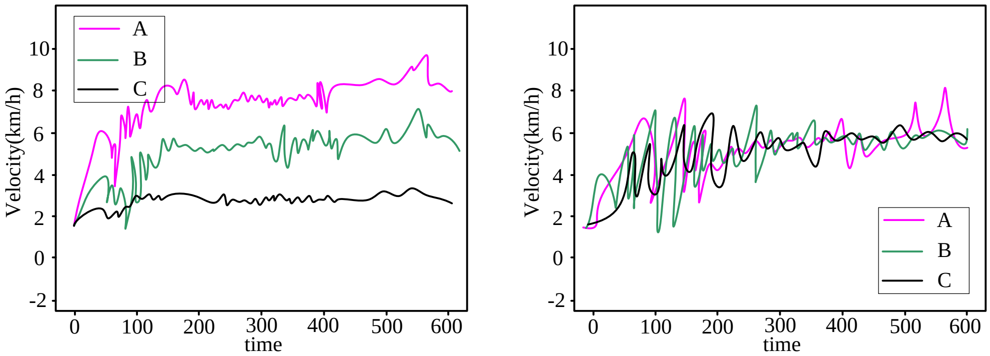
Therefore, it can be obtained:

$$\tau_{com} = \begin{bmatrix} \left(\frac{1}{2} m_1 + m_2\right) g l_1 \cos\theta_1 + \frac{1}{2} m_2 g l_2 \cos(\theta_1 + \theta_2) \\ \frac{1}{2} m_2 g l_2 \cos(\theta_1 + \theta_2) \end{bmatrix} \tag{12}$$

In the above formula, m_1 represents the weight of the exoskeleton thigh, m_2 represents the weight of the exoskeleton calf; l_1 represents the length of the exoskeleton thigh, and l_2 represents the length of the exoskeleton calf; θ_1 represents the angle between the thigh and the horizontal line, θ_2 represents the angle between the thigh and the calf; τ_1 represents the moment of the hip joint under the gravity compensation module, and τ_2 represents the moment of the knee joint under the gravity compensation module.

3. Rehabilitation Training Exercise Speed Results

In order to verify that the method can realize the action of the patient, three experiments were carried out on the patient on this basis. The patients in group A did not participate in rehabilitation training, the patients in group B were patients who actively participated in rehabilitation training, and the patients in group C were patients who normally participated in rehabilitation training. On the basis of the three groups of test data, the patient's exercise rate curve was drawn, as can be seen in Figure 3:



A. According to the speed change chart of the speed assist algorithm
B. The speed change chart of the path control algorithm

Figure 3. Velocity change graph under two different algorithms

In the speed assist algorithm, the change of moving speed is shown in Figure 3A. Pink refers to the speed at which the patient did not participate in the rehabilitation training, because the patient is passive, so the patient's moving speed depends on the exoskeleton, so the patient's moving speed is 3 km/h. Green indicates that the patient is actively participating in rehabilitation training, and over time, the patient's movement speed would become faster and faster, finally reaching 6 km/h. Black represents normal participation in rehabilitation training, and over time, the exoskeleton's movement speed would be reduced to 2km/h, which is the slowest speed selected by the exoskeleton. In the confrontation with the exoskeleton, the patient would greatly slow down the movement speed of the exoskeleton, and to a certain extent ensure the smooth progress of the rehabilitation training.

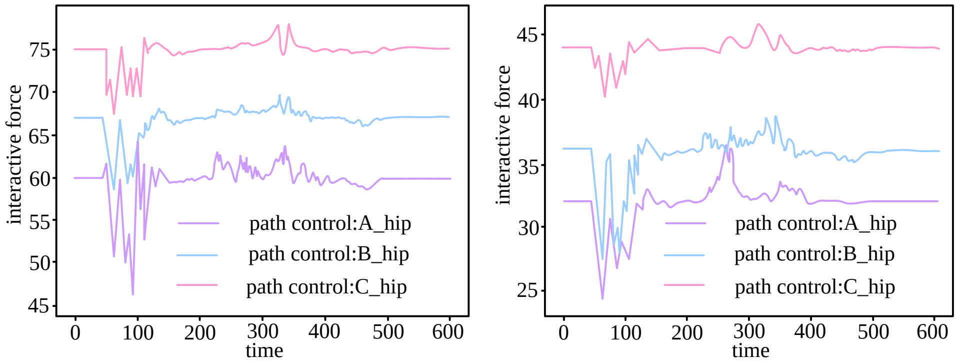
And the speed profile of the route control algorithm is shown in Figure 3B. The pink color represents the speed curve of the patient not participating in the rehabilitation training. After some time, the speed curve stops at 3 km/h. Green represents that the patient actively participates in rehabilitation training and makes active attempts, and the final result is: 3 km/h. On the other hand, black represents that the patient actively participates in rehabilitation training and makes negative efforts, and finally reaches 3 km/h. The patient's movement speed was maintained at 3 km/h in all three cases, because when the patient actively participated in the rehabilitation training and made positive efforts, the patient's own movement speed exceeded 3 km/h. However, because the moving speed of the window does not change when the target point is found, the exoskeleton always stays at 3 km/h. Therefore, the interaction force between the exoskeleton and the patient would increase, which would affect the patient's own movement speed, resulting in the patient's movement speed remaining at 3km/h. The speed comparison of the two algorithms is shown in Table 1:

Table 1. Movement speed of the two algorithms

Group	Path control algorithm motion speed	Speed at the speed auxiliary algorithm
Group A	3 km/h	3 km/h
Group B	3 km/h	6 km/h
Group C	3 km/h	2km/h

As shown in Table 1, in the analysis of the speed test of the rehabilitation training, it is found that when the patient is exercising by himself, the path control algorithm cannot adjust the movement speed of the patient according to the movement speed of the patient, but adjusts it according to the movement of the patient. However, the simple motion speed analysis cannot guarantee that the patient has fully invested in the rehabilitation training. Therefore, under both methods, the interaction force between the patient and the exoskeleton is collected, and whether the patient participates in the rehabilitation training to the greatest extent can be judged from the strength and change trend of the interaction.

In order to ensure that the patient can fully invest in the rehabilitation training, the interaction between the human body and the exoskeleton under different algorithms was tested by using the interactive force to obtain the model. The results of three different experiments are compared using pure passive position control as a reference. Figure 4 shows the interaction of humans and exoskeletons under the path control algorithm.



A. The interaction force between the thigh and the exoskeleton
B. The interaction force between the lower leg and the exoskeleton

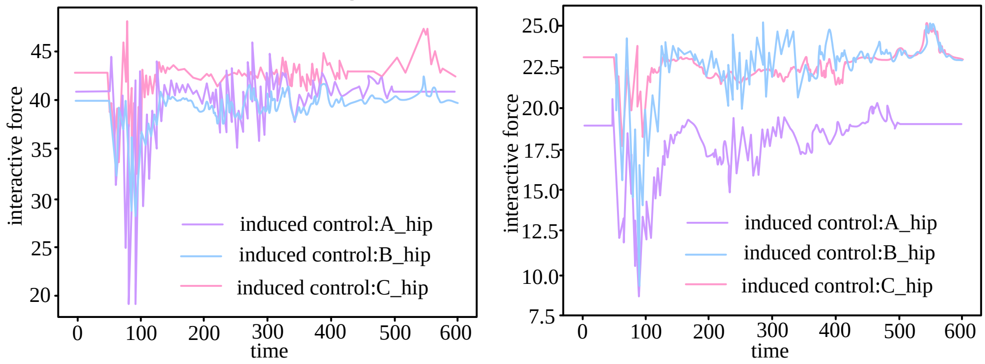
Figure 4. The interaction force between the human and the exoskeleton in the path control algorithm

Figure 4A is the change curve of the interaction force between the patient's thigh and the exoskeleton, and Figure 4B is the change curve of the interaction force between the patient's lower leg and the exoskeleton. The pink line represents that the patient did not participate in the rehabilitation training, the blue line represents that the patient actively participated in the rehabilitation training, and the purple line represents that the patient normally participated in the rehabilitation training. It can be seen from Figure 4 that without actively participating in rehabilitation training, the interaction force between the human leg and the exoskeleton is maintained at 45 N~65 N, with a peak value of 64 N. The interaction force between the legs and the exoskeleton is maintained between 23 N and 35 N, with a maximum of 35 N. When the patient actively participated in rehabilitation training, the interaction force between the leg and the exoskeleton increased significantly, reaching 27 N to 39 N, with a maximum of 39 N. Table 2 shows the interaction force between the path control algorithm and the exoskeleton:

Table 2. Interaction forces between the path control algorithm and the exoskeleton

Group experiment	Interactive interval	Peak interaction	Average interaction
Group A thigh	45N ~ 65N	65N	55N
Group B thigh	68N ~ 78N	77N	77N
Group C thigh	58N ~ 70N	72N	66N
Group A calf	23N ~ 35N	36N	34N
Group B calf	40N ~ 47N	47.1N	48N
Group C calves	27N ~ 39N	38N	34N

It can be seen that the interaction between the human body and the exoskeleton would increase significantly after the patient actively participates in the rehabilitation training. Therefore, in rehabilitation training, since the path control algorithm cannot match the speed of the patient, there would be a certain difference between the speed of the human body and the speed of the exoskeleton when the patient actively participates in the rehabilitation training, which creates more pressure, which results in a greater interaction. In the speed assist algorithm, the interaction between human and exoskeleton is shown in Figure 5.



(a) Interaction force between exoskeleton and thigh

(b) Interaction force between exoskeleton and lower leg

Figure 5. Interaction force between human and exoskeleton by speed assist algorithm

As shown in Figure 5(a), the interaction force between the patient's thigh and the exoskeleton was maintained between 20 N and 45 N, with a maximum value of 45 N. In Figure 5(b), the interaction force between the patient's calf and the exoskeleton was maintained between 8 N and 20 N, with a maximum value of 20 N. When the patient actively participated in rehabilitation training and performed negative exercise, it was found that the interaction force between the calf and the exoskeleton was maintained between 27 N and 42 N, with a maximum value of 25 N. The interaction between the thigh and the exoskeleton is calculated according to the velocity, see Table 3:

Table 3. Interaction force between human and exoskeleton by speed assist algorithm

Group experiment	Interactive interval	Peak interaction	Average interaction
Group A thigh	20N ~ 45N	46N	35N
Group B thigh	25N ~ 35N	33N	32N
Group C thigh	27N ~ 42N	45N	31N
Group A calf	8N ~ 20N	24N	16N
Group B calf	10N ~ 25N	26N	17N
Group C calves	15N~ 25N	26N	26N

From this, it can be seen that during the rehabilitation training, the movement speed of the patient can be synchronized with the movement speed of the patient without any pressure, so the interaction between the legs and the exoskeleton would not change much.

4. Conclusions

Neurological dysfunction is a common disease of stroke, which would have a certain impact on the quality of life of patients. Therefore, how to effectively alleviate the patient's neurological dysfunction, improve the patient's quality of life, and better restore health is an urgent problem to be solved at present. According to the current condition of hemiplegic patients, combined with the research progress of rehabilitation exoskeleton robot, a lower limb rehabilitation exoskeleton system is proposed. Starting from the current rehabilitation needs and the shortcomings of the current rehabilitation treatment strategies, a method that can make patients participate in rehabilitation training as much as possible is proposed, and it is tested and applied in the existing system. During the system experiment, due to the limitation of instruments and platforms, only three control experiments were set up, and the interaction between the human body and the exoskeleton was not analyzed under other motion rate conditions. Therefore, multiple controlled experiments can be considered to study human-human interactions at different movement rates.

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