The Application of Computer Assisted Rehabilitation Environment in Rehabilitation Evaluation and Training

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Abstract: **Objective**: To summarize the background, working principle and application of the computer assisted rehabilitation environment in the study of modern rehabilitation medicine treatment, and to clarify its advantages in the rehabilitation of limb movement disorder. **Methods**: Through the network retrieval articles in PubMed database, China CNKI database, VIP database for virtual reality environment (virtual reality environment, computer assisted rehabilitation environment (computer assisted rehabilitation environment), movement disorders, rehabilitation (Dyskinesia rehabilitation, retrieval time for 1999 and 2015, excluding low correlation, repeatability, old literatures, a total of 31 articles were reviewed. **Results**: The virtual environment of the dual task of the computer assisted rehabilitation environment is helpful to improve the ability of the patients' limb movement to make the interaction, interest and safety of the rehabilitation training. Computer aided rehabilitation environment has important clinical value and broad application prospects in the field of rehabilitation. It is worth further development and application in the field of rehabilitation of limb movement disorders.

With the development of social economy, the aging process is accelerating, the prevalence of chronic diseases is increasing, and higher requirements are put forward for the form and capability of rehabilitation services[1]. As sports training is more and more valued by clinical rehabilitation treatment, this kind of training has begun to be applied to clinical rehabilitation treatment, providing great help for patients' rehabilitation[2]. Rehabilitation evaluation runs through the whole process of rehabilitation treatment, plays an important role and is also a necessary part of rehabilitation treatment[3]. Computer Assisted Rehabilitation Environment (CAREN) is a rehabilitation system consisted of a motion platform, a virtual environment (projection screen), motion capture, and central control. The CAREN system can analyze, evaluate and rehabilitate gait. Compared with the traditional 3D gait analysis, it is fast, real-time, accurate, quantitative and safe. The application of CAREN rehabilitation system in gait evaluation is rarely heard in China, but it often appears in major scientific journals and research reports abroad. This paper aims to summarize the background, working principle and application of CAREN in the research of modern rehabilitation medicine, and to clarify its advantages in the rehabilitation of limb movement disorder.

1. Brief Introduction to CAREN

Computer Assisted Rehabilitation Environment (CAREN) is designed and manufactured by Motek medical research company in Holland. The company's definition is a rehabilitation system that integrates hardware and software for human movement including personal information entry, evaluation, and functional training. CAREN provides patients with a virtual reality for visual, auditory, tactile, and motion platform interference in the environment. Moreover, it requires patients to complete various scene tasks, improve limb movement ability, achieve movement peace and control, and realize movement rehabilitation[4].

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2. Research Situation of CAREN

CAREN was invented in the 1990s. According to relevant records[5], early CAREN had limitations in its use. As a technical means, it is mainly aimed at the rehabilitation of limb disorders in stroke patients. There are also a few special reports showing that CAREN is also applied early in the military to improve the adaptation of amputees to the affected limb[6]. The working principle of CAREN is based on the application of virtual reality technology which can create and experience the computer simulation system of virtual world. It uses a computer to generate a simulation environment that is a multi-source information fusion of interactive 3D dynamic scenes and physical behavior system simulations that enable users to integrate into the environment[7].

Eerden[8] is the first scholar to describe CAREN. In the 1999 CAREN introduction, he described that its development is to measure in detail the data that computer-controlled motion platforms interfere with the human motion system. Then, it inputs the obtained motion data into the simulated human body model, calculates and evaluates the instantaneous strength of the joints and the degree of muscle activation.

Through the reaction time model, the subject's motion power points can be inferred, and the main problems leading to functional disorder in the motion system can be found to determine the joints and muscle groups needed for rehabilitation. Through correction, CAREN can make the patients with insufficient muscle strength realize the secondary adaptation in the system. This compensatory strategy for the patients can enhance their rehabilitation confidence with better treatment attitude. Eerden holds that CAREN is not only a testing and training environment, but also an excellent tool for studying motion control, with almost infinitely exploration of patients' movements. CAREN has a 6-degree-of-freedom motion platform. Meanwhile, it can measure the patients' biomechanical information feedback through inertial sensor, force plate, electric goniometer, biological pressure feedback device and motion measuring device with sensor, to help patients establish a new limb motion feedback as early as possible. X (horizontal axis), Y (direct axis) and Z (vertical axis) are axes in three directions. The three axes are perpendicular to each other to form three planes: the longitudinal plane (YZ plane), the transverse plane (XZ plane) and the horizontal plane (XY plane). M1–M4 are four markers used to establish the default rotation axis[9] (Fig. 1).

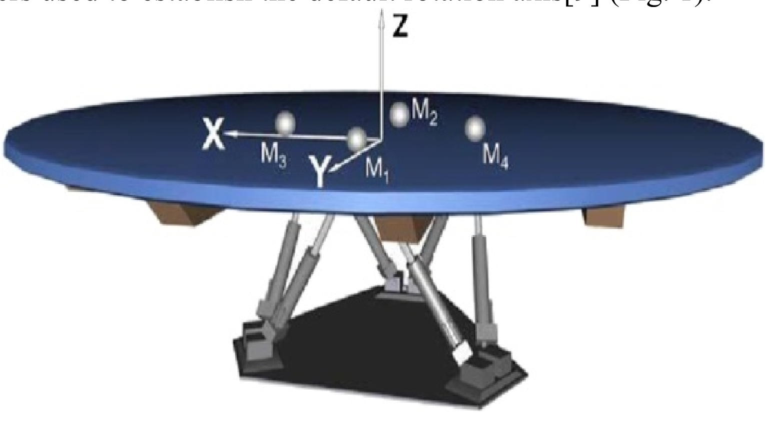

Fig. 1. 6 Degree-of-Freedom Motion Platform

Giggins'[10] paper describes different types of biofeedback rehabilitation, in which points out that CAREN is based on the principle of biofeedback system that has been widely used in rehabilitation. It can feed back many unknown biological information to patients, which can be divided into biomechanical feedback and physiological information feedback. Physiological information feedback includes neuromuscular physiological information feedback (such as electromyography), cardiovascular information feedback (such as heart rate, blood pressure, etc.) and respiratory system information feedback. Biomechanical feedback includes motion test, posture control and body strength evaluation. Inertial sensor, force plate, electrical goniometer, biological pressure feedback device and motion measuring devices with sensor can be used to provide biomechanical information feedback. For example, a pressure plate can be used to provide patients strength feedback and posture control feedback. These biomechanical feedback testing systems are integrated into CAREN.

3. Application of CAREN in the Rehabilitation of Limb Movement Disorders

Virtual reality technology can provide patients with opportunities to experience in a complex physical environment, but the body does not take any risks. This can provide them with opportunities to participate in training, or provide them with opportunities to experience body postures and walking[11]. El Maksoud[12] studies human-computer interaction in virtual reality. Its main purpose is to find an optimal solution that enables patients to simulate real-life walking in a virtual environment. Through clinical research, he has found that stroke patients can quickly receive and adapt to CAREN training methods. They can walk into a virtual environment and perform gait training at any angle on a 6-degree-of-freedom motion platform according to individual needs.

In the comparative study of CAREN and ground walking, Gates DH[13] compares the training changes of thigh amputees walking on the ground with that of treadmill walking in computer-aided virtual reality environment. The subjects are 7 patients with traumatic thigh amputation and a control group of 27 normal persons, who walk on the ground and CAREN treadmill at the same speed. The observation of the spatiotemporal, whole-body kinematics, and kinematic variation parameters collected in all experiments shows that there is little difference in lower limb kinematics (<2.5 (○)). Walking in the pelvis and trunk of CAREN' s control group shows a drop in coronal and sagittal planes, while those with a thigh amputation do not. Both groups show an increase in step width while walking on the treadmill at CAREN, but only a slight change in movement. The results of this study indicate that treadmill training in a virtual environment should be highly similar to the results of a control group.

Isaacson[14] has confirmed that CAREN can help wounded soldiers recover from physical functions and limb disorders. Isaacson pointed out in the article that the wounded soldiers in war are different from the ordinary disabled people because the wounded parts of soldiers injured by bombs are random and the injuries are varied and complicated. Thus, more innovative rehabilitation tools are needed for systematic treatment to help them return to the army quickly or be able to live normally. CAREN can meet the demanding requirements for treating wounded soldiers, and its characteristics enable them to enter a clinical environment close to real life. By collecting and analyzing kinematic and kinetic data, therapists can design rehabilitation plans.

Barton[9] believes that the function of the motion platform is usually limited to the study of human balance. Since rotation is only allowed to rotate according to the specified axis, when running to the platform surface, it appears to be over-constrained in freedom of movement, and can not perform composite movement. Thus, the control mechanism of proximal joint cannot be directly studied. Barton believes that the rotation axis of the CAREN motion platform has three planes, and the rotation of the support surface around the joint axis creates interference. The motion platform rotates around the reconstructed joint axis instead of the specified axis. Thus, CAREN can accurately adjust the motion platform to any position through the rotation axis, and can overcome the angular limitation of other platforms. This is its advantage, and also the reference control system of the CAREN motion platform.

Kizony[15] holds that patients with neurological deficits are usually accompanied by the dual dysfunction of limb movement ability and motor ability. Thus, he adopts CAREN to design a dual task to study the feasibility of training the gait of stroke patients in a virtual environment. He has selected 10 elderly people with stroke from the community and healthy elderly people of the same age as the control group for gait comparison test. The subjects walk on the motion platform while setting up a virtual grocery aisle on the screen. The first time they are asked to pass the aisle (single task), and the second time to complete the purchase while walking (dual task). The results show that the stroke group walks slower and shorter than the healthy group in both experiments. However, in the single task, the pace of the stroke group changes greatly and the step length is short, while in the dual task of adding the purchase, the pace and step of the stroke group have increased, and the failure rate of the dual task is lower than that of the single task. It can be seen that setting up a dual-task virtual environment through CAREN helps to improve the patients' limb movement ability and their walking training effect.

4. Advantages of CAREN Compared with Traditional Rehabilitation

4.1 Improving the Ecological Validity of Rehabilitation

Traditional clinical rehabilitation methods have been criticized for limiting ecological validity because their purpose is to improve daily behavior. However, the correlation and similarity between the training system and the real world are relative. The simulated task may be done well, but it is difficult to effectively apply it in real life[16]. CAREN' s virtual reality can make up for the shortcomings of traditional simulation training, and can provide patients with the required virtual reality scenes for testing and training. Virtual reality environment not only looks like the real world, but also presents the real environment completely in the virtual environment through strict scientific control and duplicated scene control, which increases the reality and complexity of simulation tasks. In this way, the rehabilitation training of patients is more close to the real world and has more clinical value[17, 18]. The interaction between CAREN and patients is enhanced, so the ecological validity of rehabilitation is improved. Sessoms PH[19] observes changes in the rate of center of gravity shift and gait improvement in subjects receiving vestibular motion therapy with CAREN. Patients in both groups get trained once a day. One group does CAREN and traditional vestibular therapy once a day for 12 times, while the other group only performs CAREN once a day for 12 times. The two groups are compared with each other and then compared with data from a healthy control group performing similar tasks in CAREN. The results show that those who participate in 12 CAREN training have a significant improvement in gait speed ($P = 0.014$). Besides, their scores on gravity shift are similar to those of healthy control group ($P < 0.001$).

4.2 Control Training Difficulty and Advanced Training

One of the advantages of CAREN is that it can effectively control the stimulation of training, and can also arrange advanced training according to the rehabilitation of patients. Many patients with limb dysfunction cannot perform simulated tasks in the real environment, such as moving boxes and shooting, and the difficulty of movement is difficult to control. However, in CAREN, the corresponding training can be designed according to the injury degree, and there is no limit of space and props, so the difficulty can be effectively controlled by computer software. Kim[17-20] focuses on the development of virtual training systems. He once designed a system for moving boxes, in which he divided the movement into six difficulty levels. In the virtual environment, the first difficulty is to lift the box and then put it down, and the second level is to lift it and turn it to the other side. The third is to set up multiple stacked boxes in a virtual environment, with the subjects moving one at a time to the other side. The fourth is that subjects lift the box and walk a straight path on the runway to the designated place. The fifth is that subjects lift the box and walk on the uneven road and put it in the designated place. Schultheis et al.,[21-23] use CAREN to provide virtual driving training to patients with traumatic brain injury. Initially, they only require patients to "drive straight" and not deviate from the runway. With the improvement of rehabilitation level, advanced training requires patients to "drive to accelerate and decelerate". Later, they set up other vehicles on the road, asking patients to "drive to avoid", and finally patients can "drive easily on the highway". Experiments have confirmed that CAREN' s virtual reality movement rehabilitation can not only effectively restore the patient's movement ability, but also conduct effective difficulty control and advanced training. At the same time, CAREN' s immersive visual and auditory system can also help improve patients' limb movement ability.

4.3 Real-time Training Feedback

Deutsch[24-26] uses CAREN' s real-time motion feedback to perform motion rehabilitation for patients with stroke and upper limb dysfunction. In order to enhance the upper limb mobility of patients, Deutsch thinks of a way to use the real-time motion feedback of CAREN to image on the projection screen. The patients are asked to draw on the large screen through the movement of each angle of the upper limb. By recording the movement track to draw various patterns, patients are required to wear data gloves to play the piano or keyboard on the screen when finger training. The results show that most patients have improved their upper limb mobility, and one can even use his injured hand to complete a tie. CAREN' s real-time training feedback mainly benefits from excellent motion capture system and camera data analysis system, the former plays a greater role. Patients wear markers and data gloves with motion sensors for training. With the support of the camera system, we can monitor the amplitude, angle and number of movements in real time. To enable patients to meet the training requirements, movement trajectory can be preset on the screen, so that they can intuitively identify the training goals and observe their completion in real time. This puts forward a higher requirement on the quality of the patients' completed movements and can evaluate their movements at any time. Patients will be recorded if they are lazy or not careful during training.

4.4 Environmentally Safe without Space Restrictions

During the rehabilitation training for the patients with motion dysfunction, it is necessary to ensure their safety and avoid secondary injuries. CAREN is an independent and closed virtual training environment, which is different from the training in the real environment with various risks. Moreover, during training, CAREN has a suspension rope hanging on their body to avoid falling. In the real environment, for the limitation of objective factors, the training place cannot be changed frequently, and patients are generally treated in hospital rehabilitation centers. However, repeated training at the same place for a long time will reduce their initiative. Instead, CAREN can eliminate space limitation and let patients experience different training environments. For example, in the "driving experience of stroke patients" mentioned above, it is unrealistic for them to drive in person for training. Allowing patients to get rehabilitation training in a driving environment can effectively improve their enthusiasm. CAREN can also cooperate with the changes of the sports base to simulate the uneven road surface and allow patients to train in virtual environments such as "mountain climbing" and "skiing".

4.5 Making Full Use of Patients' Cognition and Instinct

To help stroke patients regain their movement ability, Sohlberg[27-32] has designed a game for the virtual system. In a room surrounded by fire, patients are asked to evacuate according to the suggested route, including crouching, crossing obstacles, walking, dodging and so on. The virtual fire and alarm sound have caused visual and auditory stimulation to patients, stimulated their limb movement ability and instinct, and improved the innervation ability. Some stroke patients have completed movements that they cannot do in the game.

5. Expectation

5.1 Reducing Rehabilitation Costs, Reproducible Rehabilitation Model

At present, the one-to-one rehabilitation model consumes a lot of manpower and material resources. A therapists can only treat one patient at a time, which is time-consuming and labor-intensive. The wide application of CAREN may change the current situation and reduce rehabilitation cost. In the future, after a large number of clinical trials, the rehabilitation system will be more perfect. Moreover, CAREN has real-time feedback monitoring, controllable training difficulty and perfect evaluation system, which can enable therapists to enter data into CAREN after accurate diagnosis. Patients are allowed to train themselves in the system, and treatment only needs to be monitored. In this way, changing from one-to-one to one-to-many and from passive rehabilitation to active rehabilitation can improve the effect and efficiency of rehabilitation.

5.2 Tele-rehabilitation

The tele-rehabilitation mentioned here is not the traditional one-to-one rehabilitation mode realized by the computer video of patients and therapists. The tele-rehabilitation mentioned here is not the traditional one-to-one rehabilitation realized by the computer video of patients and therapists, but requires patients to have a CAREN first. CAREN' s motion-capture, camera, gait and other systems can be used to evaluate and record patients' conditions, whether at home, in the community or in nearby hospitals. Therapists analyze the data to make a rehabilitation plan, even without having to communicate with patients. The evaluation data of patients is the most intuitive description of their condition, and the big data analysis of CAREN is the key to realize tele-rehabilitation.

5.3 Game Upgrading, with Enhanced Immersion

Advances in computer graphics can help us create any virtual modes we need, even design familiar family environments with holographic imaging. The development of the game industry and software can further enrich CAREN' s game mode and task difficulty. At present, the development of 4D movies provides support for the upgrade of CAREN virtual reality. The most ideal virtual reality technology can make patients completely immersed in CAREN, and can not distinguish the real environment and virtual one. In such an environment, patients have no space and geographical restrictions, and are more close to the real world, so that the sports skills acquired by training can be directly applied to real life.

6. Conclusion

At present, the earliest relevant literature is found in a case study published by De Groot et al[33] in 2003. For the first time, they apply the CAREN rehabilitation to gait training for patients with fibular aplastic anemia wearing different orthoses. The research team of this study shows that CAREN system can enable patients to evaluate the wearing effect of different orthotics in a relatively safe simulation environment, and provide certain reference for doctors and prosthetic technicians to select orthotics for patients. After half a year of periodic gait evaluation and training, De Groot et al find that CAREN can help to adjust and improve orthotics. Besides, it can also help patients to adapt to different types of orthotics, improve the fitness of the original unsuitable ones, so that patients can more easily accept orthotics. The results of this treatment show that CAREN has the potential to evaluate the effects of orthopedic shoes, orthoses, and lower limb prostheses. The treatment of this system can be conducted as part of the amputee rehabilitation program. From this point of view, this study also achieves similar results. The different evaluation results of the four groups of patients are consistent with the advantages and disadvantages of different foot plates. This indicates that CAREN rehabilitation system can effectively evaluate the gait adaptability of different foot plates of the leg prosthesis and draw relatively reliable conclusions.

In 2006, J. G. Barton et al.,[34] applied CAREN to gait training of stroke patients in the later treatment. The research shows that the patients after stroke can get the effect which is difficult to be achieved by general indoor or outdoor training in the virtual environment of CAREN rehabilitation system. However, in the world, the proportion of soldiers and civilians who suffer from severe limb disorders due to frequent regional armed conflicts and terrorist attacks is 3.5% - 14%[25]. It can be seen the prevalence of limb dysfunction continues to rise, both in civilians and military. Though patients can survive after treatment, it still needs long-term follow-up rehabilitation if they want to return to their normal independent living ability and basic movement ability. Thus, finding a rehabilitation system or method that can improve the treatment enthusiasm and effect of patients has become the focus of rehabilitation field in recent years. Gottshall KR et al., [16] use CAREN combined with traditional motion therapy. In this research, four patients with mild traumatic brain injury receive additional CAREN training on the basis of traditional vestibular therapy, twice a week for 6 weeks. After 6 weeks, all patients have shown improvement in balance, gait, and visual communication. This confirms the effectiveness of CAREN in rehabilitation training for brain injury related defects.

CAREN has a wide range of applications and has certain advantages in the field of rehabilitation of limb movement disorders. It is worthy of further experimental research and promotion and application in the field of rehabilitation of limb movement disorders.

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