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Application of BCI in Muscle Regeneration Tissue

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Abstract: The application of brain-computer interface (BCI) technology in the medical field continues to expand, and the research on muscle regeneration tissue has gradually attracted attention. BCI is a real-time computer system that converts electrical signals into control instructions and can interact with the external environment without the use of the nervous system and muscles. This paper aims to explore the application of BCI in muscle regeneration tissue, including its potential in motor control, rehabilitation therapy, neuromuscular interface, etc. In this research, the advantages and problems of brain-computer interface (BCI) technology pertaining to the promotion of muscle function recovery, the improvement of movement disorders, and the assistance of neuromuscular reconstruction are discussed. This is accomplished by evaluating the interaction mechanism between BCI technology and muscle regeneration tissue. At the same time, the future development direction of BCI in the field of muscle regeneration tissue is also explored. This includes the technical innovation, clinical application, and multidisciplinary collaboration that are all included in this discussion. Patients are anticipated to experience improved rehabilitation and quality of life as a result of the utilization of BCI in muscle regeneration tissue, which offers a novel approach to the treatment of muscle injury and disease.

1 Introduction

Regenerative muscle tissue refers to biomaterials or cellular therapies that repair or replace muscle tissue. Clinical practice often involves muscle damage and disease, which impairs motor performance and quality of life. Muscle regeneration tissue research has advanced with tissue engineering technologies; however, there are still many hurdles. Brain-computer interface (BCI) technology, a new neural interface technology, converts brain impulses into computer-readable instructions to allow direct brain-device interaction.

BCI can monitor and interpret motor intent brain impulses and translate them into orders or stimuli for nerves or muscle tissues that contract. BCI with muscle tissue regeneration can better control injured muscles, improving exercise rehabilitation. The application of BCI in the fields of motor control and rehabilitation therapy has been widely studied and verified, but its application in muscle regeneration tissue is still in its infancy. We will review the application of BCI in muscle regeneration tissue from some technical fields, such as virtual reality technology, sensors, and so on.

2 Methodology

2.1 PLV-Spatial Filter and LSTM Classifier

For timing signals such as EEG, many adaptive machine learning models have been developed in recent years, among which Phase Locking Value (PLV) spatial filtering and Long Short-Term Memory (LSTM) classifiers can improve signal quality and classification accuracy in the following ways: Enhance useful signals: PLV spatial filtering can highlight signal features related to a specific task or state by analyzing phase synchronization between signals. [1] PLV spatial filtering improves signal quality by removing noise, enhancing clarity, and reducing artifacts for better classification.

STM (scanning tunneling microscope) classifiers excel at processing time series data by capturing long-term dependencies, crucial for classifying biological signals like EEG (eletroencephalo-graph) and EMG (electromyography). They leverage temporal dynamics for improved accuracy and adaptively learn features to handle diverse, complex signals. LSTM has a certain ability to prevent overfitting. [2]

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DoF Full name	DoF coded
Thum_Roll	TR_1
Thumb_Inner	TI_2
Thumb_Outer	TO_3
TI_Abduction	TI-Abd_4
Index_Inner	II_5
Index_Middle	IM_6
Middle_Inner	MI_7
Middle_Middle	MM_8
MI_Abduction	MI-Abd_9
Ring_Inner	RI_10
Ring_Middle	RM_11
RM_Abduction	RM_Abd12
Pinky_Inner	PI_13
Pinky_Middle	PM_14
PR_Abduction	PR_Abd_15
Palm_Arch	PA_16
Wrist_Flex	WF_17

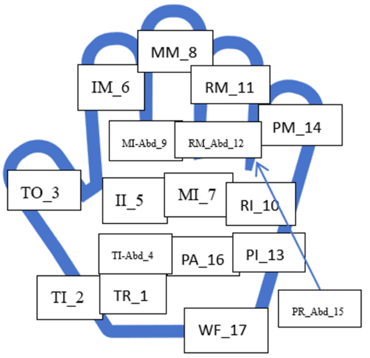

Figure 1. (Right) DoF location for recording hand movements. (Left) Correspondence between the full name of the CyberGlove sensors and our coded names

2.2 Application in intuitive control within virtual environments

PLV spatial filtering enhances EEG or EMG signals in virtual environments by reducing noise and improving signal quality for better classification. LSTM classifiers process time series data, capturing long-term dependencies to interpret user intentions in these environments. By learning these patterns, LSTM classifiers can convert processed biological signals into control instructions for objects or operations in the virtual environment.[2] The LSTM classifier then converts these signals into control commands. This approach enhances accuracy and response speed, enabling natural and smooth user interactions. However, in practical applications, many factors need to be considered, such as the stability of signal acquisition and the influence of individual differences on signal characteristics.[3]

The existing investigation uses LSTM-RNN (Recurrent Neural Network) to predict hand kinematics from muscle activations captured through surface EMG [2]. The trained model was applied to the actual scene to predict the kinematic information of the hand in real-time in Figure 1. Models can be integrated into relevant control systems or rehabilitation devices to enable muscle activation-based hand movement control or evaluation.

2.3 Flexible Carbon Nanotube Sensors Embedded in Conductive Polymers

Motion sensors track real-time movement, aiding rehabilitation by providing recovery data for therapy adjustments and analyzing athletes' movements in sports. Help coaches to understand the movement skills of athletes and mechanical characteristics so as to carry out targeted training and improvement.[4] Wearable carbon nanotube sensors monitor movement in real-time and aid in early disease diagnosis and monitoring.

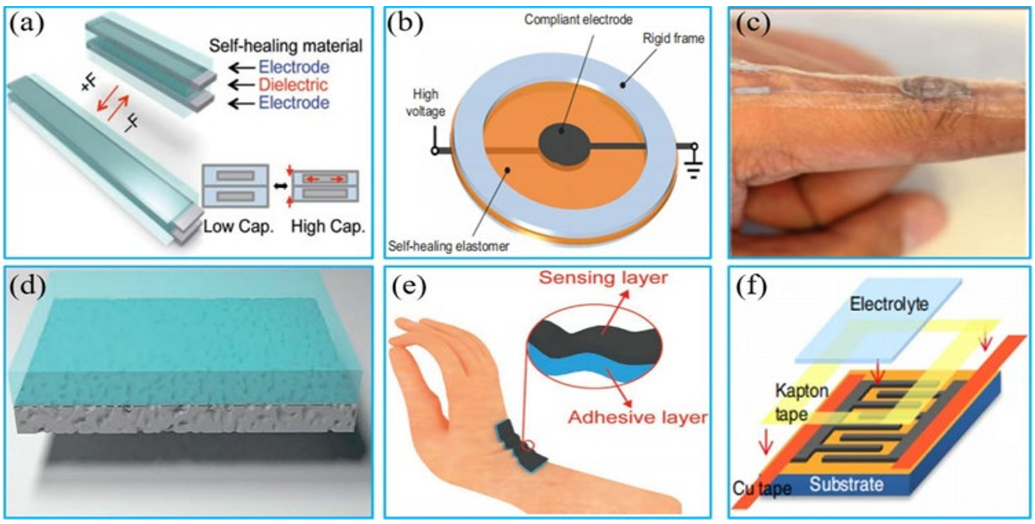

Figure 2. Novel materials for flexible sensors: (a) aminopropyl terminated PDMS (b) aminomethyl siloxane (c) silicon PEIE is introduced into oxane, (d) 3D graphene is transferred to PDMS (e) rGO with CNT is added to polyurethane and (f) supercapacitors[4]

The new materials for flexible sensors obtained in Figure 2 provide important support for sensor performance improvement, application expansion, and reliability in practical applications and promote the development of flexible electronic technology. Carbon nanotubes have excellent electrical properties, and their high conductivity and large specific surface area make the sensor more sensitive to small physical changes.[5] The sensor accurately detects body movements, adapts to skin for better fit, and reduces noise with a stable conductive network from carbon nanotubes. This helps to reduce the impact of external environmental factors on the sensor signal, reduce noise interference, and thus improve the accuracy and reliability of the data.[4]Multi-modal sensors detect various physical quantities, like pressure, strain, and temperature, through well-designed structures and functions. In this manner, we are able to get a greater quantity of information concerning human activities, enhance our capacity to comprehend and record human behaviors in a complete manner, and further enhance the precision of the data. [6]

2.4 Development of a Novel BCI System

BCI systems are being developed to improve rehabilitation and assistive technology interfaces. These systems analyze brain signals and operate external devices using powerful signal processing and machine learning. [7] By combining modern BCI systems with muscle regeneration therapies, rehabilitation can be more efficient and individualized.[8] These technologies tailor therapy to each patient, increasing rehabilitation outcomes. The therapy is safe and effective due to real-time feedback and adaptive control. In addition, we have found some new ways to integrate BCI technology, such as Brain-muscle interface (BMI), which directly converts brain signals into muscle activation for controlling prosthetics or restoring movement in arms and legs. Studies have found that long-term use of BMI can help patients improve motor skills and neurological recovery. There is also Brain-skeletal muscle interface (BSI), an approach that combines BCI and electrical stimulation techniques to directly stimulate muscles for rehabilitation and restoring motor function. BCI is now capable of non-invasive rehabilitation, and some BCI systems use non-invasive methods, such as electroencephalography (EEG), to collect brain signals. This method avoids the risk of surgery and makes the recovery process safer.

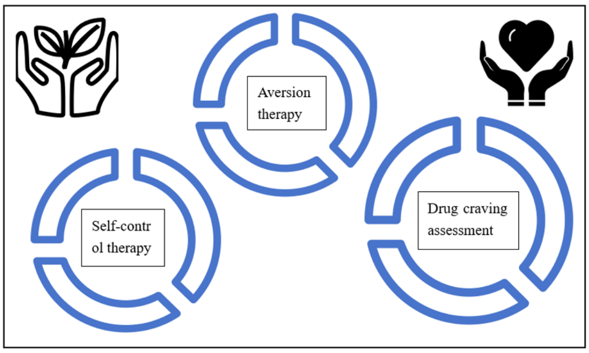

Figure 3. UI of Drug Addiction Rehabilitation Training System [7]

2.5 BCI in VR Environments

Through the provision of immersive therapy and real-time EEG-based feedback, the integration of BCI and VR leads to an improvement in the user experience. In addition to enhancing the user's capacity to manage the virtual world through the use of their brain signals, this real-time connection makes it possible for rehabilitation activities to be significantly more effective. (5) [7] Figure 3 illustrates that in the field of drug treatment, we are able to designate corresponding treatment courses for patients by utilizing virtual reality in conjunction with self-control therapy, aversion therapy, and drug desire evaluation.

2.6 Application of VR in Rehabilitation

VR and EEG provide a strong muscle regeneration rehabilitation tool. VR simulates rehabilitation scenarios, allowing patients to practice and improve motor abilities safely. EEG readings give real-time brain activity feedback, making training more precise and effective.[9] This tailors rehabilitation activities to each patient's demands, maximizing therapeutic efficacy and speeding recovery. The interaction between BCI and muscle regeneration can be done via EEG, using electrodes affixed to the scalp that record the electrical signals generated by brain activity. By analyzing specific waves in these signals, researchers can observe how the patient's brain responds when they imagine muscle movements or actually perform them. It can also be done with functional magnetic resonance imaging (fMRI), which scans the brain to see which areas are active during muscle regeneration activity. This method can provide a three-dimensional picture of activity inside the brain and help researchers understand which brain regions are associated with muscle regeneration.

3 Application of BCI based Muscle Regeneration

3.1 Application Examples

BCI-based muscle regeneration strengthens muscle control neural networks and aids rehabilitation by letting patients operate avatars or robotic objects in VR via brain signals. A stroke survivor can utilize a BCI device to operate a VR hand. [7] BCI helps patients control hand movements in VR, increasing motor skills and muscle coordination. This interactive technique makes exercises fun and tailored with real-time feedback, improving recovery. VR-ULE uses a wearable exoskeleton with MI recognition software. The system framework is shown in Figure 4.

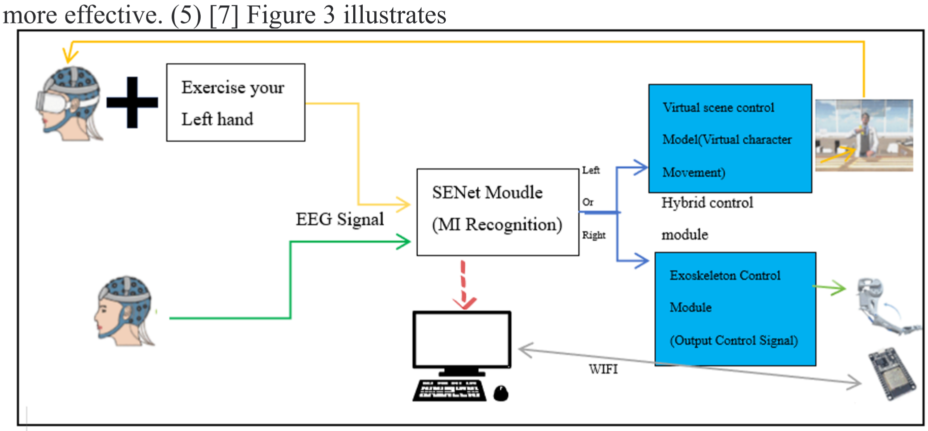

Figure 4. The architecture diagram of the upper-limb rehabilitation exoskeleton system (VR-ULE).[10]

The wearable exoskeleton includes a functional backpack for control modules and an upper-limb robotic arm. The MI recognition software has a VR scene cue module, a CNN+SE (Convolutional Neural Network+Squeeze Excitation) module, and an online hybrid control module. The VR scene cue module is used to provide patients with a strongly immersive virtual MI cue during the CNN+SE model training stage.[10] The CNN+SE module amplifies EEG signals to classify motor intentions, while the online hybrid control module provides feedback and controls the virtual character or exoskeleton motion based on MI signals.

3.2 Technical Advantages

PLV-spatial filtering and LSTM classifiers enhance BCI systems' signal quality and accuracy, enabling precise control of muscle regeneration devices and effective real-time feedback. Combined with VR, these systems provide a safe, adaptive environment for rehabilitation.[2]

4 Future Prospects

4.1 Future Applications of BCI Technology in Muscle Regeneration

BCI technology enables real-time monitoring of brain and nerve activity, facilitating personalized neural rehabilitation and muscle regeneration. By analyzing how the brain responds to different exercise intentions, rehabilitation therapists can adjust the intensity, frequency, and manner of training to maximize muscle regeneration and functional recovery.[11] BCI provides biofeedback for muscle control and regeneration, allowing patients to adjust training. Few studies explore psychological factors predicting motor rehabilitation potential after stroke without BCI. Stinear and Byblown published an update of their model achieving better prediction (75% accuracy) considering only shoulder abduction and finger extension in 2017, the age of the participant, the severity of stroke (assessed by the National Institute of Health Stroke Scale), and the presence of motor evoked potentials. [11]

4.2 Potential for Interdisciplinary Collaboration

Rehabilitation doctors and therapists can develop personalized rehabilitation training programs according to the specific needs and clinical conditions of patients. They work with BCI technologists to apply BCI techniques in rehabilitation training to help patients recover muscle function more effectively.[5]

5 Conclusion

The integration of PLV-spatial filtering and LSTM classifiers represents a significant advancement in biomedical signal processing. By improving signal quality and classification accuracy, these techniques pave the way for more reliable and effective applications in BCI, virtual environments, and rehabilitation systems. Future research should focus on optimizing these methods and exploring their full potential in various biomedical fields.

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