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Affective-Visual-Voice-Feedback Immersive Brain-Computer Interface Integrating EEG-Based Motor Imagery and Generative AI for Stroke Patients

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Introduction: Stroke patients often use the exoskeleton system in a passive mode during the rehabilitation period. Motor imagery (MI) is controlled by capturing rhythmic signals, which promote the activation of motor nerves in the brain and accelerate their remodeling. This study aims to evaluate the effectiveness of a robot-assisted system combined with proprioceptive neuromuscular facilitation (PNF) training compared to conventional treatment in subacute stroke patients. Affective, voice, and visual feedback can enhance the MI system's effectiveness.

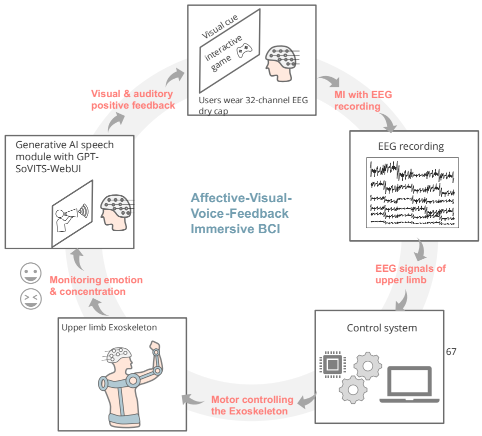

Figure 1: *Affective-Visual-Voice-Feedback Immersive Brain-Computer Interface.*

Material, Methods and Results: Patients in good condition wear a 32-channel EEG dry cap during the BCI rehabilitation process. EEG recordings are used to monitor brain activity and control the BCI. We have developed a new BCI system that integrates motor imagery, positive emotion recognition, visual-voice immersive environment, and generative speech AI, combined with an upper limb exoskeleton, to facilitate brain-computer loop rehabilitation and explore the relationship between neuroplastic changes and motor function recovery (see Figure.1). The detailed methods are as follows: **1. MI Recognition**: Event-related resynchronization energy changes in the primary motor area of the cerebral cortex are used to determine whether the subject is performing MI. **2. Development of a visual-voice immersive environment:** A Generative AI speech module, GPT-SoVITS-WebUI, is applied to imitate the voices and timbre of relatives to praise and encourage patients while using the upper limb exoskeleton to play an interactive rehabilitation game. **3. Emotion and Concentration Recognition**: Concentration indicator (β_{avg}/α_{avg}) and Valence-Emotion indicator ($\alpha_{F4}/\beta_{F4} - \alpha_{F3}/\beta_{F3}$) are used to monitor patients' mental states during the new BCI system usage. These indicators, together with the immersive environment system, are employed to enhance the effectiveness of interactive rehabilitation.

The visual and auditory feedback are based on the allows the brain to communicate directly with external devices without the involvement of the peripheral nervous system and muscle tissue, allowing paralyzed people to do so without the need for physical movement. Limb MI can activate the plasticity of brain cells as real limb movements and can accelerate the repair of neural functional connections between limbs and the brain from EEG recording. Results from three subjects showed that using this system effectively improved concentration by 16.67% compared to not using it. During the rehabilitation task period, the average results indicated that the subjects successfully performed motor imagery 52.67% of the time. Positive emotions were detected 39.3% of the time, with approximately 12% of positive emotions lasting more than 10 seconds.

Conclusion:

The proposed BCI system can recognition module to instantly identify the patient's movement intention, feed the results back to the interactive scene to control the movement of interactive objects and the state of the brain topography, forming a real-time interactive closed-loop control structure.

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