Virtual Reality Trunk Muscle Training System

Problem Description

Currently, there is a need for intensive research efforts in the fields of geriatrics, exercise science and physiotherapy to address rising age-related and cost-intensive health care problems. Low trunk stability is a major cause of concern to those that are aging and individuals suffering conditions such as spinal cord injury (SCI) or stroke. This is due to the fact that trunk muscles are primarily responsible for maintaining the stability of the human spine against multidirectional external forces. Weak trunk muscles cause instability (in sitting and standing balance) which may affect the performance of daily activities such as reaching and object manipulation, and have been shown to increase the risk of severe falls by 4-5 times. This causes both a decrease in quality of life, and a large medical cost to Canada, nearly $2 billion annually. The importance of trunk stability in everyday life is a no-brainer; individuals who suffer from movement disorders like paraplegia often value regaining trunk stability more than having the ability to walk. Current mitigation techniques used in trunk rehabilitation traditionally include balance/lower extremity resistance training. However, this type of training poorly translates to real life which leads to insignificant improvements in balance and daily activities. To counter this problem, real-time electromyography (EMG) acquisition (Biofeedback) during trunk muscle rehabilitation should be implemented to see how the target muscles react to different training mechanisms. Specifically, this allows for precise targeted training as real-time EMG data will communicate if the proposed training exercise is effectively recruiting/training the intended muscles.

Design Solution

This engineering design project aims to design and develop a rehabilitation protocol to improve trunk stability using real-time EMG acquisition and a biofeedback display. There are 4 main objectives to this design:

1. Create a comfortable, low-cost, easy-to-use, wearable device that obtains movement and muscle activity from the rehabilitation patient.
2. Implement a Virtual Reality environment that will display live biofeedback from the EMG data obtained from the wearable, which will allow the user to see if the muscles are being activated effectively
3. Develop a training game that will utilise EMG and movement data from the wearable and provide an enjoyable and effective training experience for the user.
4. Automate and utilise the SpaceBall, a seated aerotrim device, as a mechanism to elicit additional trunk muscle activity using its 2 degrees of freedom. The movement of the Spaceball will correspond to a training application implemented in virtual reality which will prompt the user to perform several exercises through visual cues.

The target audience of this device can be defined as individuals suffering from conditions such as spinal cord injury (SCI), muscular dystrophy, and similar conditions that cause underactive trunk muscles. Our design allows for patients to sit in a pneumatic aerotrim gyroscope device (Spaceball) that will move in two degrees of freedom, pitch and roll. This will cause tilting to be more difficult, effectively training the user’s trunk. The design includes a wearable belt that implements EMG circuits and an accelerometer to track muscle activation in 5 different muscle groups and tracks the user’s movement. Two WiFi enabled microcontrollers are used, one is used as a control system for Spaceball movement, and one responsible for sending EMG and accelerometer data to the phone app. The Virtual Reality training module created in Unity 3D is implemented as a VR application where the user can view their progress with live biofeedback charts, and play a game where they must move their trunk to dodge obstacles and collect rewards. This design provides the user with many options to train their trunk muscles effectively, and the live biofeedback allows them to view their progress and modify their exercise as necessary.

The design was evaluated to ensure that all the needs of the stakeholders were being met. One of the most important factors to take into consideration was how a wearable would affect the user physically, such as using a flexible, soft, fabric to allow for minimal chafing against the skin and overall comfort, to not interfere with the movements of the trunk, and to use minimal hardware in order to reduce the overall weight of the belt. The relative ease of use was also taken into consideration, as key trunk muscles were identified to characterize trunk muscle activation; this reduced the number of electrodes needed significantly making it easier to set up as well as to use. Another important consideration was how the technology interacts with the user. The biofeedback process must operate fast enough for real-time feedback and data update, otherwise the biofeedback display will lag and not provide accurate support for training. As the VR is updated in real-time and quickly, the patient should not feel disoriented or uncomfortable with the movement in space and the changing display. The VR headset should not be too heavy, or impair patient movement. The patient should also be able to receive biofeedback in multiple modalities to accommodate all abilities and accessibilities. Finally, the SpaceBall should provide customizable training difficulty that would not be available in other protocols, such that the SpaceBall is a necessary and efficient use of patient therapy time.

Application

The wearable EMG belt contains the circuitry, power, and microcontroller used to obtain the EMG data of the targeted muscles and the orientation of the user. It contains an ESP32 Microcontroller, which provides the ADC, basic digital filtering, and WiFi communication to phone. The belt (Figure 1b) uses four 9V batteries and a 3.7V LiPo battery to power the microcontroller, an Accel+Gyro IMU to provide orientation of the trunk, and 5 EMG acquisition circuits (Figure 1a) with instrumentation amplifiers for high input impedance, band pass filtering, and rectification.

Figure 1. Sensor size and circuitry for EMG sensing (A), and complete wearable belt device (B).

Virtual reality was used to reinforce patient training and display biofeedback information to the patient. It also provides patients with visual display and interaction with the training protocol and training games. Currently programmed for Android devices, using Unity 3D and C#, the patient is prompted with selection menu (Figure 2a) options such as Calibration, Play, Live Data, Quit and Manual Override. These options will be selected using the timed gaze input modality, so that no hand movements or external devices are required to interact with the VR space. Auditory and visual feedback will be provided to ensure a smooth and accessible VR experience. In ‘Live Data’, patients and therapists can select and see muscle activity corresponding to each group in real-time (Figure 2b). Choosing ‘Play’, users are taken to the game mode, where EMG data is displayed as they play an interactive exercise game. The Spaceball is an aerotrim, a human gyroscope, in which a person is seated in a chair placed inside (Figure 2c). The Spaceball moves in two degrees of freedom, pitch and roll, powered by 2 pneumatic pumps (Figure 2d). This device provides the patient with unexpected movement and slip simulation to help activate, train, and strengthen the trunk muscles. The Spaceball is controlled via microcontroller through commands sent through the VR game, and can be customized as needed by the therapist.

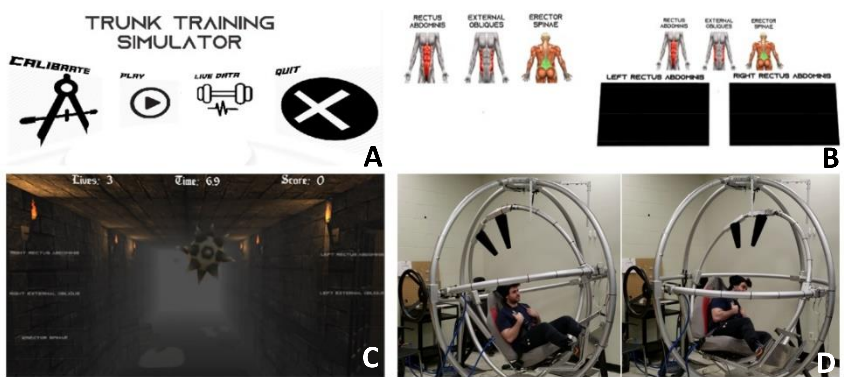

Figure 2. Virtual Reality features, including menu (A), biofeedback (B), game mode (C), and connected Spaceball modality (D).

Implementation

The Virtual Reality Motion Simulator Trunk Muscle Training System allows for an effective training application by monitoring muscle activity in real time such that the user can determine if their muscles are being trained effectively. Implementation of this system for rehabilitation would greatly reduce the amount of training time needed as both clinicians and patients will be able to monitor EMG activity and use it to determine exercises suited for them. This system also gamifies a training program providing a fun, interactive method in which users can train their trunk muscles. To increase the impact and usefulness of this solution, reducing the weight and form factor of the wearable belt is of the highest importance. In addition, data logging of the EMG muscle activity and corresponding accelerometer data could be very useful to a therapist/doctor, as this could help identify key areas of weakness leading to focused training procedures and more effective therapy. For patient and electronic health record (EHR) protection, a patient log-in and data security should be implemented, such that the user will have a log in and will have local data saving for future interpretation by the therapist or other qualified practitioner. Going forward, primary and secondary market research will be used to improve the solution and evaluate effectiveness. Patient experience was evaluated using surveys and questionnaires, and the biofeedback output was also compared to an industry validated EMG acquisition device, but further validation, verification, and user surveys are needed to ensure this solution meets and exceeds market needs.