Development of Virtual Games with Functional Electrical Stimulation for Post-Stroke Hemiplegia

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This work aimed to develop virtual reality (VR) games to be used in combination with contralaterally-controlled functional electrical stimulation (CCFES) therapy – in order to enhance the latter's effect in restoring hand function to hemiparetic stroke survivors. Future work will be to investigate the clinical feasibility and efficacy of this combination treatment.

BACKGROUND: CCFES therapy is a novel intervention that enables stroke survivors to open and close their paretic hand by delivering surface electrical stimulation to the paretic finger and thumb extensors (Fig. 1). Stimulation is proportional to the degree of unimpaired hand opening as detected by an instrumented glove. Thus, volitional opening of the nonparetic hand produces stimulated opening of the paretic hand. CCFES therapy incorporates features considered to be important for motor recovery and for promoting neuroplasticity: linking motor intent with motor execution of paretic hand opening, bilateral symmetric movement, proprioceptive and somatosensory feedback, and repetitive practice of hand opening and functional tasks. Pilot studies of CCFES have demonstrated positive evidence for efficacy in both chronic (> 6 months post-stroke [1]) and subacute (< 6 months [2]) stroke patients.

We believe that adding VR games to CCFES may optimize the treatment and improve outcomes. Existing CCFES therapy includes an at-home, self-administered repetitive hand opening task cued by periodic auditory signals. The exercise is performed for 12 weeks, 5 days per week, for two 1 hour sessions daily. While the home exercise encourages high repetition, the exercise task is suboptimal for motor relearning, as it is not goal-oriented and does not require much motor planning or close attention. Thus, CCFES therapy may be enhanced by incorporating engaging and goal-oriented VR games. Such games have independently shown promise in pilot studies for restoring hand function [3], but have not been combined with functional electrical stimulation before.

METHODS: Principles from agile software development [4] were used to design the games in collaboration with clinician-experts in stroke rehabilitation, followed by frequent and iterative evaluations by both clinicians and hemiplegic stroke survivors with hand impairment. Subjects were all stroke participants or able-bodied research personnel involved in two ongoing CCFES therapy clinical trials. Each game was first evaluated by a clinical team (3 physiatrists, 2 occupational therapists, and a biomedical engineer) to ensure that the following criteria are satisfied: 1) The game is fun, intuitive, and has lasting replay value. 2) Difficulty ranges are appropriate. 3) Game goals can only be achieved with targeted motor skills and untargeted or compensatory movements cannot be used to provide an advantage. 4) Performance measures are provided to motivate stroke survivors to improve upon their prior performance. 5) Visual presentation is considerate of possible stroke-related visual and cognitive impairments – not complex or distracting. 6) Performance in the game can be aided by CCFES. These criteria were adapted from and commonly observed in VR therapy literature [5]. After each game was refined by clinician evaluations, stroke survivors evaluated the games based on the same criteria. Evaluators' comments were used to refine each game and evaluations were repeated until all criteria were met. We developed the following games using the Unity game engine (Unity Technologies, San Francisco, CA) to run on personal computers and bend sensors to track hand motion (Phidgets Inc, Calgary, Alberta, Canada).

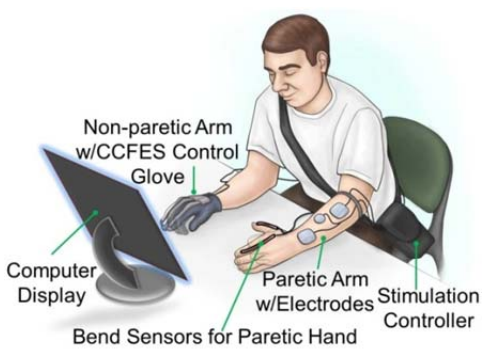

Figure 1. Setup for VR games with CCFES

Paddle Tennis (Fig. 2) – Subjects control a vertically moving paddle to bounce a ball past the automated opponent's paddle. This game facilitates the practice of repetitive, controlled hand opening/closing. Paddle position is controlled by degree of paretic hand opening. Difficulty is adjusted manually or automatically by changing paddle size, ball speed, and opponent speed. Automatic difficulty changes are made by an algorithm that decreases difficulty if paddle hit rate is below 50% or increases difficulty if the rate is above 70%. Performance feedback is provided via score, hit rate, and number of motor repetitions.

Skee Ball (Fig. 3) – This game facilitates practice of controlling hand opening speed. The ball's launch speed is controlled by hand opening rate. Also, after each trial the ring target moves up or down the board, requiring different hand opening speeds. Difficulty is adjusted either automatically (with the same algorithm as Paddle Tennis) or manually by changing the target ring diameter. Performance feedback is provided via score, accuracy, and number of motor repetitions.

Marble Maze (Fig. 4) – This game requires users to rotate a series of mazes to guide balls out and into a bucket. Maze rotation is controlled by the degree of hand opening. Besides targeting range of motion and motor planning, practice of maintaining hand posture is also required since it takes time for a ball to roll across the maze walls. Difficulty is adjusted by changing bucket size and by the number of balls (max of 10) within a single maze. These changes can be made manually or automatically via preset stages. Performance feedback is presented via completion time and by points scored for progressing toward past checkpoints, exiting the maze, and for hitting the bucket.

FUTURE WORK: Case series feasibility studies of VR+CCFES will be followed by randomized controlled trials. Treatment will consist of therapist-administered sessions at the clinic and self-administered sessions at home. The clinic sessions will include 45 minutes of VR+CCFES games and 45 minutes of occupational therapy. The home sessions will require the participant to play VR games for two 1-hour sessions daily (20 minutes per game for each of the 3 games).

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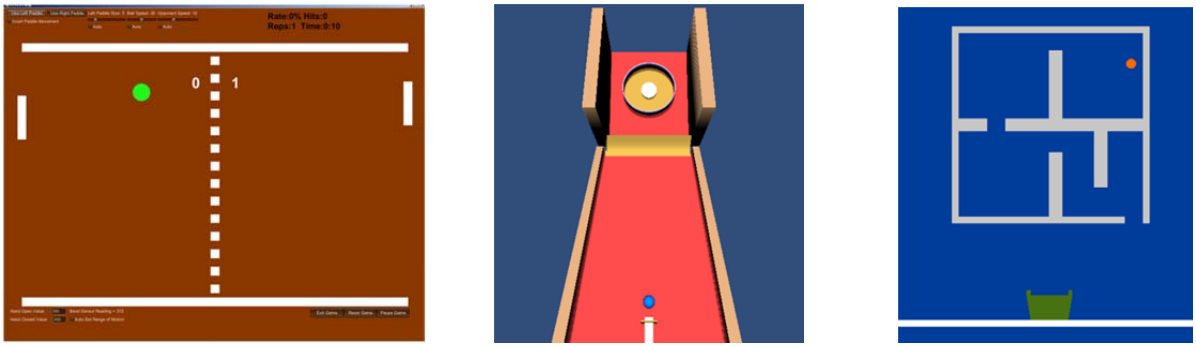

A) B) C)

Figure 2. Screen capture for A) Paddle Tennis, B) Skee Ball, C) Marble Maze