NeuroRehab + The "Fun" Factor

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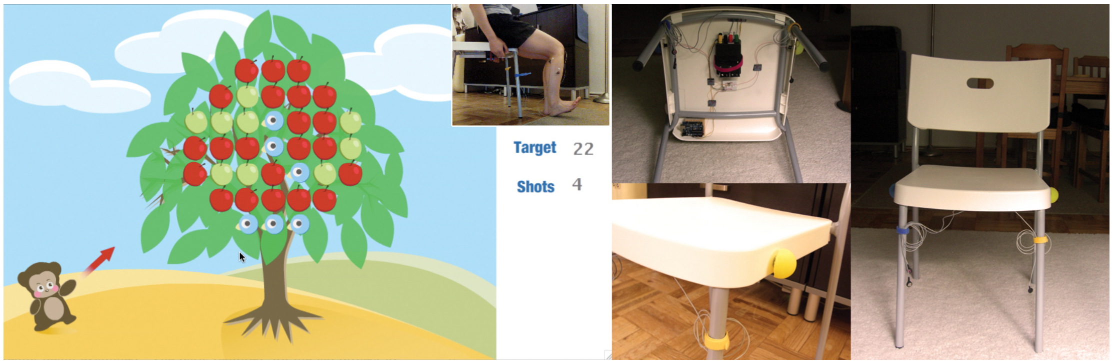

Figure 1: *Final game (left) and controller (right) designed for foot-drop*

Abstract

Rehabilitation processes for neurological traumas have traditionally relied on physical therapy that involves repetitive exercises. While proven to be effective, these processes can become monotonous for patients and labor-intensive for therapists. Recent advancements in robotics and game consoles have alleviated these issues but are generally limited to specific motor skills, while excluding other types of deficits. This paper considers this limitation by focusing on a deficit known as the foot-drop and by exploring how the "fun" factor can be effectively incorporated into rehabilitating the condition. As a preliminary stage of this exploration, a device comprised of a game and a controller using muscle-based electrical impulses has been developed. The implementation of this device demonstrates potential benefits for the neurologically impaired with successful integration of muscle-based electrical impulses and game technology. Further testing is required to determine whether the integration of game-play can provide a "fun" incentive, which results in increased adherence to exercises that are typically arduous and repetitive.

Keywords: games, neurorehabilitation, rehabilitation, physical therapy, biofeedback, electromyography

1 Introduction

Paralysis is the most frequent disability resulting from neurological impairment. Those who suffer from hemiplegia (paralysis of one side of body) or hemiparesis (one-sided weakness) often have difficulty in activities of daily living (ADLs), including walking and grasping objects [NINDS].

Rehabilitation for those who have disabling injuries or illnesses that have affected the brain or spinal cord is also known as *neurorehabilitation*. The ultimate goal of neurorehabilitation programs is not to cure but to improve the quality of life by helping patients regain functions required for ADLs. To achieve this, rehabilitation professionals help those suffering from paralysis and motor impairments by designing programs that rewire the brain, a process also known as *neuroplasticity*. There is a general consensus among experts that it is important for such rehabilitation programs to be carefully directed, well focused and repetition-practiced [NINDS]. Also, while repetition is important to achieve cognitive learning, repetition with feedback and the understanding of what is necessary to achieve specific goals are helpful in developing problem-solving skills [Carr and Shepherd 1998].

Massed-practice therapy that emphasizes repetition has proven to promote recovery [Levine]. However, it can become labor-intensive and require close interaction, especially for patients who are severely impaired. As a consequence, the physical demand makes therapists prone to various injuries and extreme fatigue [Hidler et al. 2005]. The introduction of robotic devices, such as the MIT-MANUS and ARM-Guide [Thomson 2000; Hidler et al 2005], addresses these issues. One of the advantages of using robotic rehabilitation devices is that it can be automated to assist in interventions, eliminating the need for close interaction and multiple therapists [Hidler et al. 2005]. Automation also means that the devices can facilitate repetitive tasks, such as gait training and active reaching. In addition, robotic devices are capable of assessing the patient's progress over time by providing accurate and quantifiable feedback using various variables, such as position, velocities and forces. [Johnson 2006; Hidler et al. 2005].

While the positive aspects of robotic devices have mitigated the issues of labor-intensity and over-dependency, the exercises they generate are monotonous and require higher levels of motivation for patients to persevere. Simple games like connecting-the-dots have been implemented into the earlier robotic devices to engage the patients [Thomson 2000]; and more recently, advances in game consoles have extended the possibilities of games that can be played in conjunction with motor-skill rehabilitation. However, those suffering from deficits related to muscle paralysis may not have the range of movements or sensory capabilities required to navigate these devices, let alone engage in these games without difficulty

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or frustration. To meet the motivational needs of patients impaired by deficits related to paralysis, this paper explores how electromyographic biofeedback can be translated into game actions, and hence be potentially used to provide a fun incentive during neurorehabilitation. As a preliminary step to this exploration, a game and a controller using muscle-based electrical impulses are designed and developed around a common deficit known as the *foot-drop*.

For the purpose of this paper, *rehabilitation* and *neurorehabilitation* will be used interchangeably. Although the bulk of the paper is related specifically to strokes, the effects, treatments and theories presented below are applicable to those who have suffered from other forms of brain injury.

2 Related-Work

A need exists for home-based rehabilitation that confronts the challenges of costs and boredom yet also promotes exercise trainings that are diverse, complex and effective. As a response to these concerns, researchers have expressed ideas for more personal and fun therapy devices that incorporate the use of customized software and controllers and that implement games as a platform. In theory, they believe that these ideas could better sustain the motivation of the patients, especially in an unsupervised environment [Johnson 2006].

2.1 Designing Games for Rehabilitation

Studies have shown that patients tend to become lazy when relying on robotic devices for rehabilitation [Sofge 2008]. In tackling this issue, one approach is to deliver meaningful therapy via engaging video games. The underlying assumption is that patients are less frustrated, because they are focusing on controlling the objects within the game instead of waiting for the robots to assist them–which was often the objective for the earlier robotic devices [Sofge 2008]. Most of the current games designed for rehabilitation are simple, reminiscent of Atari 2600 [Sofge 2008].

2.2 Wii and Rehabilitation

The popular game console, *Nintendo Wii*, is becoming widely used not just by gamers but also by rehab patients, including stroke survivors. Using the console's motion-sensitive controller, Wii games stimulate body movements similar to traditional therapy exercises [Tanner 2008]. While getting patients to become engaged in their exercises is typically a grueling process, therapists from hospitals incorporating the Wii claim that it has given meaning to the exercises and allowed patients to become vested in therapy [Miller 2007]. In addition, they have attested that the Wii has helped patients improve endurance, strength and coordination, as well as relearn the skills required for ADLs [Tanner 2008]. Some of the current Wii games that are being played at rehab facilities are the ones involving sports, such as bowling, tennis, boxing and golf [Tanner 2008].

Currently, however, there are no clinical tests that validate the effectiveness of using the Wii [Tanner 2008]. Moreover, one limitation of the Wii is that the physical motions promoted by the controllers are still confined to the ones defined by the designers of the game. Although the Wii fosters various physical actions that resemble real-life activities, especially in the field of sports, a brain-injury survivor may not have sufficient strength, motor or sensory capabilities to move in the ways that it demands.

3 Methods

3.1 Foot-Drop

Foot-drop, a dropping of the foot due to weaknesses in the muscles of the ankle and foot, is among the common deficits related to paralysis. In many cases, those affected have difficulty lifting their ankle, moving their toes, balancing and walking. However, although a person with a foot-drop may have little to no ankle movement, the muscle impulses may still be detected depending on the extent of damage caused on the nerves [Sullivan 2008].

One technique for rehabilitating a foot-drop is to use biofeedback to activate the muscles used in dorsiflexion (or the lifting of the ankle) and to assist in the gait cycle [Sullivan 2008; Takebe and Hirohata 1980; Intiso et al. 1994]. This technique will be explored further to design and develop a game and a controller that will meet the rehabilitating needs of those impaired by the deficit.

3.2 Game Requirements

Two criteria were devised for choosing a game designed to rehabilitate foot-drop:

1. A game that would engage the patient's attention.
2. Analog data that could be administered by different degrees of muscle strengths in the ankle.

Bloon After reviewing over thirty online flash games, *Bloon* was deemed suitable for a foot-drop condition. Listed as one of the top ten addictive online games [Lim], *Bloon's* objective is to burst a targeted amount of balloons within a set number of attempts (Figure 2). For a typical user, the game is controlled by using the mouse to aim the arrow (the black arrow above the monkey character), holding down the mouse button to power the arrow, and letting go of the button to finally shoot. In this project, for foot-drop patients, it was decided that instead of using a mouse, the powering of the arrow could be a function that would be administered by the variable strengths of the muscles in the ankle.

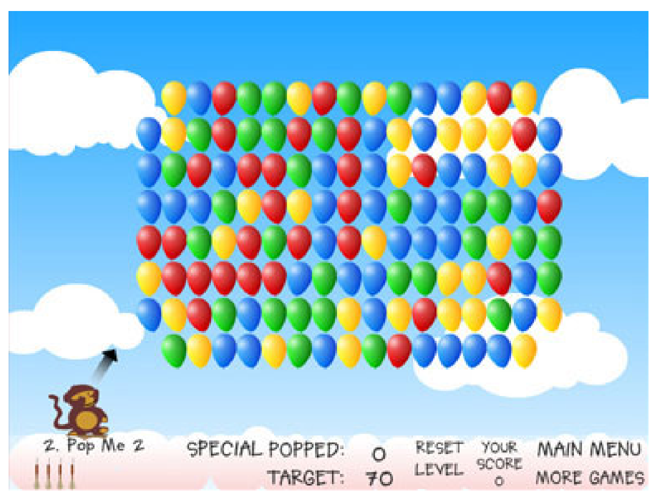

Figure 2: *Bloon.*

3.3 Controller Requirement

Mainstream video games generally require multiple actions, such as navigating a character or firing a gun, which can be triggered and controlled using buttons, joysticks and other forms of game apparatus. An appropriate controller that is designed to rehabilitate a person with a foot-drop, however, should encourage the usage of the affected foot, while controlling the elements within a game. This means that physical functions need to replace the conventional forms of game controllers. Consequentially, these two criteria were devised for the controller:

1. The controller should translate the users' movements, or the lack of, to help them communicate with the game.
2. The shape and form of the controller need to accommodate the physical needs specific to a foot-drop patient.

Single Focus: Strengthening The movements suggested in the first criteria for those with a foot-drop refers to physical functions that are still active and functional after the brain trauma. These may include arm movements, hand coordination, muscle contractions and balance.

Electromyography (EMG) To encourage the lifting of the ankle, the associated muscle, the tibialis anterior, must be activated. One challenge, however, is that the person with a foot-drop may have little to no ankle movement. Several sensors could be considered to meet this challenge, including force and flex sensors, but are generally not sensitive enough to measure the small range of motions that are produced by muscles affected by a foot-drop.

Biofeedback is a treatment technique in which people can be trained to improve their health by using signals from their own bodies [psychotherapy.com; Sullivan 2008; Chaperon 2008]. Among these signals, the one of interest to this paper is muscle tension. A surface electromyography (EMG) sensor is a biofeedback tool that measures muscle tension through electrodes placed on skin over the muscles. Even if a person were to have no sensation in the paralyzed limb, the EMG can often detect electrical impulses within the muscles.

By using EMG sensors, a person with a foot-drop could focus on strengthening their ankle by using the muscle impulses to control the elements of the game. For *Bloon*, the different degrees of muscle tensions would administer the charging of the power of the arrow.

Chair A chair was chosen as the physical form of the controller. All the technical components of the controller were mounted onto the chair, including additional buttons that may be needed to control other elements of the game.

3.4 Technical Components

Technical components used for the development are: EMG sensors, amplifier circuit, Arduino, serial-to-socket server and ActionScript 3.0 (Figure 3).

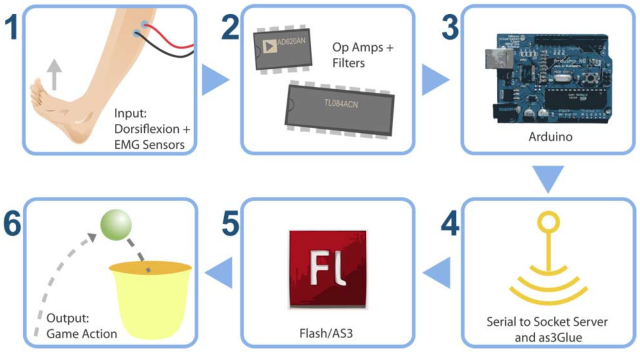

Figure 3: *Tech Components: EMG sensors, which can read muscle impulses, are placed on the affected leg (1). The input from the sensors passes through an amplifier circuit (2), which is connected to an Arduino board (3). Using a serial-to-socket server (4), Flash application (5) reads the data from the Arduino and converts it into a game action (6).*

4 Development

4.1 EMG Sensors and Circuits

A do-it-yourself method to build an EMG sensor was sought out from a bioengineeering course website and lab projects.

The course website explained that EMG outputs must be amplified to be detected by the computer and the human senses. To accomplish this, the AD620 amplifier was added onto the EMG circuit [Kirtley].

For the first version of the circuit, the information on the course website was followed (Figure 4). However, upon testing with EMG electrodes, clear and noise-free output was not attained. The second version was built following a student lab project [Godoy and Mesa 2009], using the same amplifier (AD620), in addition to TL084 chip as a filter to eliminate noise (Figure 5).

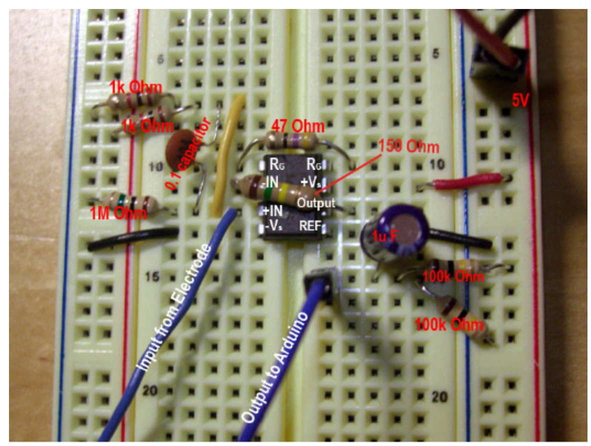

Figure 4: *First Circuit using only AD620.*

A good output was attained upon testing, indicating the flexing and resting states of the muscle, but the contrast between the high and low amplitudes was smaller than desired (Figure 6).

Troubleshoot Collaboration In an effort to troubleshoot the circuit, help was sought from a local bioengineering professor and two teams of his students. As a result, an improved circuit was produced using the AD620 amplifier and a TL072 filter (Figure 7). The testing for both circuits yielded good results, but the first team's circuit was chosen in the end. The choice was based on the number of tests conducted, the stability of the circuit, and the physical encasement of the circuit. The first team's circuit was the first one to be received and was tested more times than the second. They also provided a circuit that was encased in a plastic box, which made it easier to be mounted onto the chair (see Figure 7).

4.2 Mounting Onto the Chair

For the controller, the circuit and Arduino were mounted onto the bottom of the chair with electrode leads coming out of the front.

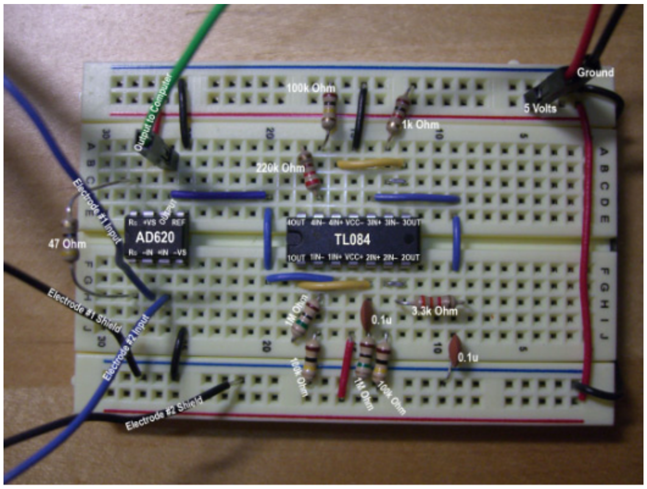

Figure 5: *Second Circuit using AD620 and TL084.*

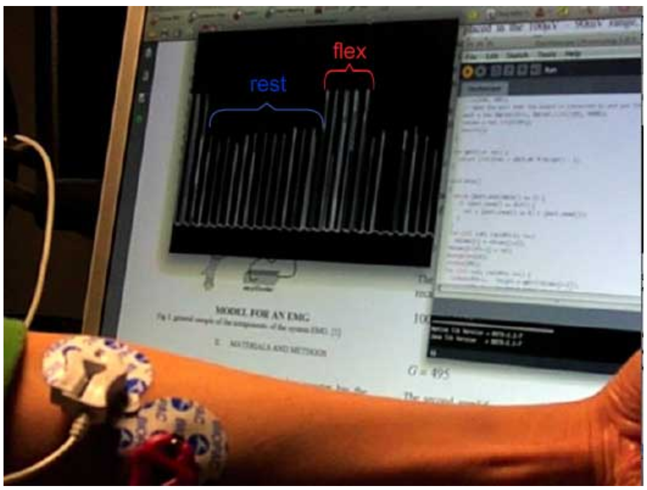

Figure 6: *Graph shows the rest and flex states of the circuit.*

Switches To allow the user to aim the arrow, momentary switches were mounted onto the sides of the chair. Sliced bouncy-balls covered them to provide a more comfortable grip (Figure 8). The left switch moved the arrow upward, and the right switch, downward.

4.3 Game

An open source game resembling *Bloon* [Quarto 2008] was rewritten using ActionScript 3.0 (AS3), and graphics were created for all the elements of the game (Figure 9). An open-source library, *as3glue* [Sjdin and Hartmann 2008], was also incorporated into the Flash application to allow communication between the game and the Arduino. Two classes were created: one for controlling the navigational and firing functions of the arm; and the other for the main document, which processed the input received from the EMG sensor.

4.4 Game

Additional features completing the game are described below:

Scoring The scoring system was developed in the same way as *Bloon*. The goal was to shoot the targeted number of apples within a set number of tries. If the target was met, the player moved onto the next level; if not, the player stayed on the same level and tried again.

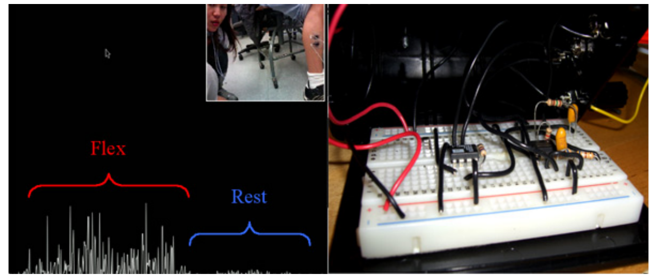

Figure 7: *Signals received from the circuit (left) and final circuit produced after troubleshooting (right).*

Figure 8: *Final Chair with Arduino board, circuit and switches mounted.*

Calibration As it is important to meet individual needs and the different levels of disability [Chaperone 2008; Potts 2008; Sullivan 2009], an adjustment feature was necessary to accommodate the various levels of strength of the participants. For this reason, a calibration feature was added to adjust the threshold of each person's muscle strength before playing the game (Figure 10).

Instructions Instructions were added in three sections of the game. First was at the intro page, where the user was presented with two main steps of the game: calibration and game-play. Second was within the calibration session, where the user was asked to relax their ankle and then to flex for five seconds. Last was just before the beginning of the game, where the user was shown an animated demonstration on how to move and power the arrow, and finally shoot the dart (Appendix 1).

5 Experiment

Participants The game was eventually tested by three participants, between the age of 23 and 28, with no prior physical impairments; and one participant, age 29, with a minor foot-drop on the left leg. The participants without a foot-drop tested the game using one leg, while the participant with the foot-drop tested on both the non-affected and affected legs.

Preparation After sitting on the chair, each participant's appropriate leg was wiped with an alcohol pad. Three electrodes were

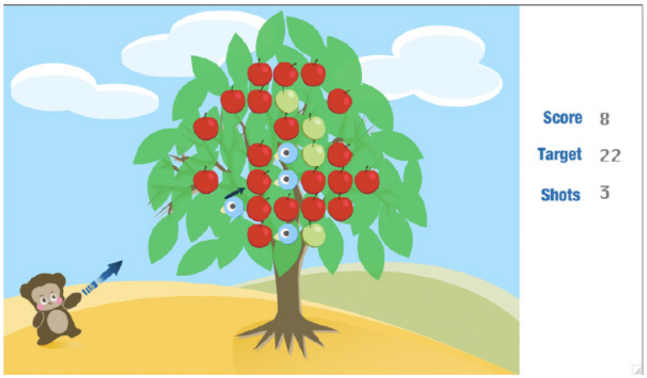

Figure 9: *Game with new graphics.*

Figure 10: *Screen shown during calibration session.*

then placed onto skin following professional advice and sensor-placement diagram of tibialis anterior [Sullivan 2008; SENIAM].

Each person was asked to follow the instructions (See Appendix 1), which was divided into two main steps: 1) Calibrate and 2) Play the game. At the completion of the game, the participants were asked to make comments on the easiness, difficulty and enjoyment of the game.

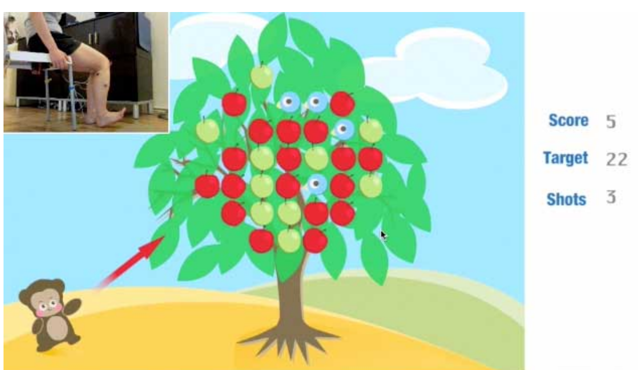

Figure 11: *Participant playing the game.*

Game-Play The buttons on the side of the chair were first pressed to navigate the arrow. The player then lifted the ankle to charge its power (Figure 12), which elongated and changed its color. As long as the ankle was lifted, the arrow repeated its cycle of charging from its minimum to maximum strengths. When the desired power of the arrow was reached, the player relaxed the ankle to shoot the dart.

Results All four participants were able to use the controller but did not advance by meeting the level-by-level objectives on their first try; however, as they became more situated and accustomed, they all completed the game as they self-initiated (without external motivation from the author) multiple re-attempts that numbered up to four times.

The following comments were made:

"The chair was simple enough to use, but the game itself was just hard and addicting enough that I knew I could and I wanted to beat it."

"Let me try again! I want to finish!"

"I can do it. It just takes few tries to get used to."

After completing the game, the participant with the foot-drop expressed some concerns of fatigue if played for a prolonged period. Another of the participants without any physical impairment also noted minor muscle soreness at the end of the game.

Time to React The time to react for foot-drop patients is slower than a normal person [Chaperon 2008]. This became especially evident when a participant with a foot-drop tested the controller and the game. Lifting the affected ankle charged the arrow in the similar way that it did with the stronger leg, but bringing the ankle down to the neutral resting state took longer, causing a delay in shooting. As a result, even when the ankle was returned to the resting state, the dart did not shoot until several seconds later. The game gave confusing feedback, as it was not responding immediately to the interaction.

To compensate the issue, a slight time delay was programmed into the shooting of the arrow to trick the user into thinking that it was shooting at the same time that the foot was at rest. As a result, more immediate feedback was achieved from the game.

6 Conclusion

The project was successful in the sense that the technical components were functional and the participants were able to communicate with the game through electrical muscle impulses. However, this was only the preliminary stage to explore whether this gaming tool could provide a fun incentive to enhance the rehabilitation experience for brain-injury survivors with a foot-drop. Conducting further experiments on a larger pool of intended users is necessary to make any conclusive assessments to the effectiveness of this tool and to the external validity of the experiment as a whole.

7 Discussion

Desired Participants In an ideal experiment, the game would be tested on a group of users with a foot-drop in various degrees of severity and are in need of improving the condition. Ongoing communications with local rehabilitation centers, therapist and patients with a foot-drop have been initiated in hopes of gathering a desired pool of participants; however, given the time constraints and limited academic resources, this was not achieved due to safety and consent issues.

Working closely with experts and patients is essential in order to understand the special needs of the unique users and improving the tool accordingly [Pitaru 2008]. With larger numbers of controls and experimental patient populations, expert and personal evaluations of the subjects via established and quantitative metrics can better characterize its usability and effectiveness.

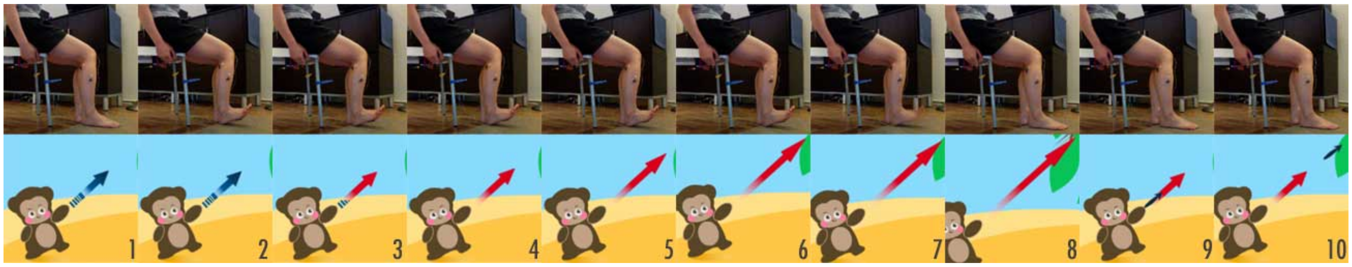

Figure 12: *Dorsiflexion (lifting of the ankle) corresponding to the charge of the arrow.*

Sitting vs. Standing Using balance as a means of aiming the arrow was initially considered; however, research and interviews with physical therapists revealed that foot-drop patients might have poor balance and difficulty standing. Also, focusing simultaneously on both balance and muscle strength may be too strenuous for a stroke patient during an exercise session [Chaperon 2008]. As these concerns arose, a decision was made to exclude balance and to have the users seated, while concentrating solely on the strengthening of the ankle.

The current chair controller, however, is limited in that participants need to be able to 1) sit up-right on a chair and 2) use the side controllers with their hands. This, of course, stands as a limitation to patients who may have physical disabilities beyond just a foot-drop.

Quantifiable Results Earlier and current robotic devices have lacked evidence on their effectiveness. If this issue is to be tackled, quantifiable data must be generated by the game to evaluate the progress of the patient. Actual figures, such as speed and strength levels, may be recorded over time within the game. Such data can assist rehabilitation professionals to appropriately analyze a patient's performance.

Cost and Portability Although a smaller and more portable device was desired, a chair was chosen to allow a foot-drop patient with poor balance to exercise the affected ankle while staying seated. As the current trend has revealed that robotic devices used for neurorehabilitation are too expensive for consumers [Potts 2008], it would be important if the patients could purchase the devices and continue therapy in the comfort of their homes. For future advancement of the tool, using cheaper components, such as more economical microprocessors other than Arduinos, can lower the overall cost of the controller. Also, instead of using a chair, it may be ideal for portability if the controller could take a smaller form. Additional options for encasing need to be explored and experimented.

Additional Features Although this can only be determined after testing on the desired users, additional features should be added to meet the individual needs and different levels of physical impediment. Options to allow therapists and patients to customize the speed and difficulty of the game; or a different "reward" used as a feedback for user interaction. Again, these considerations will be explored further once the user testing becomes reality with more expert input and larger experimental patient populations.

Appendix 1 Game Instruction

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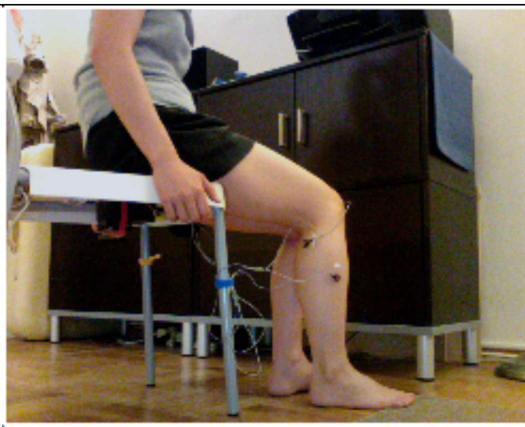
<tr><td></td><td>1. Sit and Connect
Connect the three leads hanging out from the bottom of the chair to the electrodes placed on the leg.</td></tr>
<tr><td>
</td><td>2. Intro Page
Follow two main steps: First calibrate and then play.</td></tr>
<tr><td>
</td><td>3. Calibrate
Summarizes the instruction to calibrate.</td></tr>
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</td><td>4. Calibrate: Rest
Keep the foot at rest with heel down.</td></tr>
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<td>5. Calibrate: Begin
Upon clicking “Start,” lift the ankle up for 5 seconds. A message will pop up saying, “Thank you for calibrating” and will redirect the screen to the intro page.</td>
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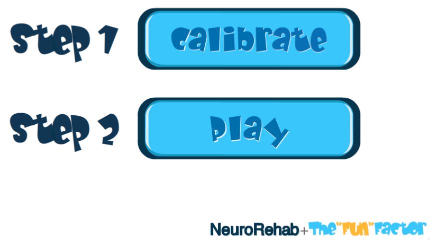
<td>
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<td>6. Move to Step 2
Click “Play” to start the game.</td>
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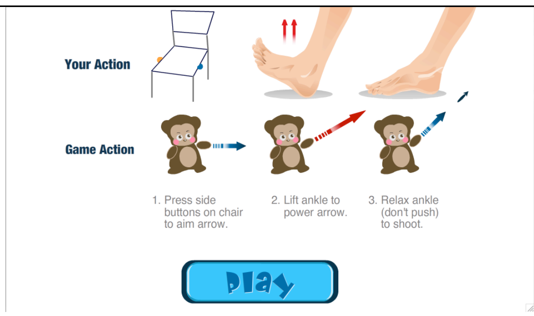
<td>
</td>
<td>7. Learning How to Play
The animated instruction shows how to aim, charge and shoot the arrow. The buttons on the side of the chair will move the arrow up or down, lifting up the ankle will power up the arrow, and relaxing the ankle will shoot the dart.</td>
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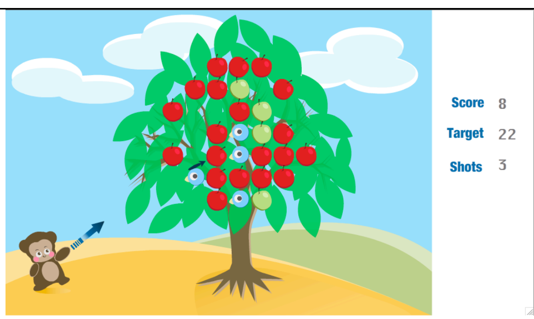
<td>
</td>
<td>8. Play Time!
Shoot the targeted number of apples within a given set of shots to move onto the next level.</td>
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Acknowledgements

I would like to thank Professor Marom Bikson and his students from the Department of Biomedical Engineering at the City College of New York for assisting me in troubleshooting and modifying the circuit involved in this project.

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