HAPTIC TOUCH TO IMPROVE MOTOR SKILLS AND SENSE OF TOUCH OF STROKE PATIENTS

By

Chow Tec Soon

A REPORT

SUBMITTED TO

Universiti Tunku Abdul Rahman

in partial fulfillment of the requirements

for the degree of

BACHELOR OF COMPUTER SCIENCE (HONS)

Faculty of Information and Communication Technology
(Kampar Campus)

MAY 2020

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Date : 9 SEPTEMBER 2020

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ABSTRACT

This project applies Haptic Technology in medical field. Stroke is the problem targeted in this project. Various stroke rehabilitation exercises exist, but effective rehabilitation exercises are still being researched. Haptic technology is being researched in this project to determine its effectives in helping stroke patients to rehabilitate. This project aims to improve stroke rehabilitation by utilising haptic touch device. The haptic device used in this project is Phantom Omni by 3D Systems. Unity game engine is used to develop the applications in this project. The applications in this project will test skills such as hand-eye-coordination, wrist flexion and wrist extension. The first application is designed for stroke patients to draw straight lines. Haptic effects are there to help stroke patients draw straight lines by pushing their stylus back on track. The second application is similar to first application. Instead of straight lines, spiral lines are to be drawn. The third and fourth application tests the strength of wrist flexion and wrist extension. Stroke patients have go against the haptic force with different levels of strength. The goal is to being able to go against the haptic force that a normal human can. All of these applications are tested on its effectiveness by having stroke patients using it.

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Chapter 1: PROJECT BACKGROUND

1.1 Introduction

The intervention of technology in medical industry has become common practice. For example, virtual reality is used to help train medical students to obtain experience in surgeries. Image processing is also used in medical industry. According to Song et al. (2019, p.9), some image processing need to be made by doctors before judging patient information from ultrasound images and they will acquire some data and information after the image processing which are the bases for them to diagnose diseases. For example, computerized tomography (CT) scan is used to detect damaged brain tissues caused by stroke (Mayo Clinic, 2020). According to World Health Organisation (2018), stroke is 2^{nd} leading cause of deaths globally, causing close to 6 million deaths in 2016. In Malaysia, cerebrovascular disease caused 7.1% deaths in 2017, taking third place in principal causes of death (Department of Statistics Malaysia, 2018, p.1). For this project, stroke is the disease chosen.

A stroke is a medical condition in which the brain cells die due to poor blood flow. It can be fatal but for those who survived, disabilities will most likely affects them afterwards. The disabilities can render the stroke survivors requiring assistance from others, making them dependent on others on a daily basis and decreasing their employability. Some of the disabilities are muscle weakness, numbness, difficulties carrying out daily activities and more. According to World Stroke Organisation (n.d.), 1 out of 6 people worldwide will suffer a stroke and a life is lost to stroke every 6 seconds.

Stroke survivors go through stroke rehabilitation to combat the disabilities. Stroke rehabilitation helps stroke survivors to regain the skills that they have lost because of the stroke. The end goal is to regain independence in daily lives. According to Mayo Clinic (2019), some of the physical activities that are part of the stroke rehabilitation are exercises that improve motor strength, mobility, affected limbs' function and range-of-motion. The duration of stroke rehabilitation varies for each person, it can last from months to years. In this project, the intervention of technology is to facilitate stroke patients in their recovery.

Several kind of devices are used to help assist in stroke rehabilitation. Some of the examples are robots, brain computer interfaces, neuroprosthesis and more (Iosa et al., 2012). Some popular current technological based solutions for stroke patients are using virtual reality and haptic exercises. The exercises that are created are able to motivate stroke patients to exercise as the exercises are fun and engaging.

1.2 Problem Statement

The current implementation of technological based applications for stroke patients are still lacking in terms of motor sensation, thus are not fully effective in guiding them.

Existing technological based applications that are reviewed do not emphasise the elements of motor sensation that can be implemented through force feedback. Force feedback simulates real-world physical touch through motorized motion or resistance while in a virtual environment such as virtual reality (VR) (Iris Dynamics, 2019). This technology allows the application to provide additional haptic elements to improve motor sensory. The behaviour pattern of healthy or having movement disorder subjects relies on the sensorimotor integration process and sensorimotor integration refers to the dynamic combination of information from sensory into voluntary motor response (Machado et al., 2010). So, sensory information is important to improve motor skills.

Most reviewed applications currently only allow stroke patients to feel the shapes of the objects while force feedback can be used to provide more ways for the virtual objects to interact with stroke patients. Besides that, stroke patients are also known to have difficulty with attention, deciding what to focus and what to ignore can be tough decisions (Stroke Association, 2012, p.3). Avoid complicated interface design in the applications will help stroke patients to focus better.

1.3 Research Question

- **Does the existing technological based applications for stroke patients is effective?**

  The existing reviewed technological based applications does not focus on motor sensory elements. The reviewed applications implement basic haptic feedback, so the sensory information for users is lesser. Sensory afferent nerves are directly or indirectly projected to cerebellum which is important in guiding motion along with regulating motor coordination (Chen et al., 2018). Users can only feel the shape of the virtual objects in the reviewed applications. Thus, a study need to be conducted to study stroke patients' challenges.

- **How to improve the current technological based application to incorporate motor sensory elements for stroke patients?**

  Motor sensory provide sensory information to stroke patients which can be helpful for them to regain motor skills. So, elements of motor sensory will be used to enhance the exercises for stroke patients which are implemented through force feedback. For example, force feedback can be used to inform users that they have made a mistake or completed something.

1.4 Motivation

Stroke is a common medical condition globally. Stroke causes many deaths but for those who survived, disabilities are another problem for them. More importantly, the disabilities that stroke survivors encountered can possibly be reduced with better stroke rehabilitation approach. Helping stroke survivors to return to normal life by regaining skills as much as possible will be a great help to the survivors and society.

1.5 Project Objectives

- **To determine the ineffectiveness factors in existing technological based application for stroke patients.**

  Analyse the factors that are ineffective in existing applications that could be avoided and finding ways to improve stroke patients' experience. This includes getting feedbacks from stroke patients and experts on the factors that are could be improved on existing applications.

- **To propose a solution that incorporates motor sensory elements to improve technological based application for stroke patients.**

  Existing applications do not utilise more of force feedback to incorporate motor sensory elements. Application that emphasises more on force feedback is proposed to help stroke patients to regain motor skills effectively.

- **To validate the proposed solution**

  A prototype will be developed and tested by stroke patients to find out the effectiveness of the proposed solution. Feedbacks will be gathered to improve it.

1.6 Project Scope

The scope of the project is to develop a technological based application with an emphasis on motor sensory elements with the intention on studying the effectiveness of this proposed solution in rehabilitating stroke patients. The application will have a simple and necessary design to prevent distractions. A solution that incorporate motor sensory elements to help them regain their motor skills and sense of touch. The recovery of motor skills will be the primary focus. The proposed solution will not cover the recovery of motor skills for lower body. Finally, the proposed solution will be tested with stroke patients.

1.7 Project Innovation and Contribution

This project emphasises motor sensory elements which aims to help improve motor skills of stroke patients. Focus of motor sensory elements implemented through force feedback is part of the innovation of this project because it can provide more elements to the exercises. So, a more effective technological based application will be made available for stroke patients.

Chapter 2: LITERATURE REVIEW

2.1 Haptic Technology

Haptic technology enables users to feel the touch of virtual objects. Some devices apply force feedback on user's hand for users feel virtual objects. This technology provides new ways for users to interact with a computer. Haptic technology can be found in mobile devices, video games, virtual reality and more. Quite a number of applications involving haptic technology for stroke rehabilitation have been designed. Haptic technology is being researched in stroke rehabilitation because it can provide different kinds of stimulations and simulations that are engaging for stroke patients. Engaging exercises are more likely to be done by stroke patients for a long period of time. Furthermore, applications that implement haptic technology can help stroke patients to exercise and monitor their results independently. These are the advantages haptic technology bring when compared to physical environment. A few applications that apply haptic technology to rehabilitate stroke patients are reviewed in the sections below.

2.2 The Labyrinth

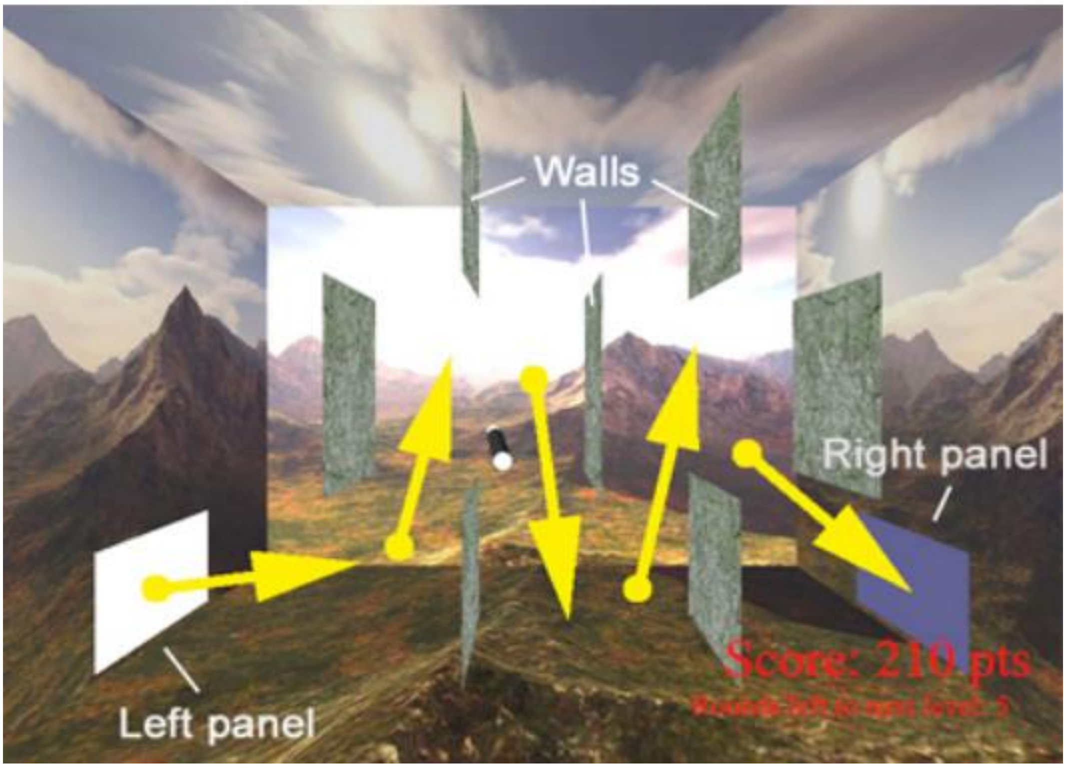

Figure 2.1 The Labyrinth by Dreifaldt, U. and Lövquist, E. 2006

2.2.1 Overview

This game requires user to grab the stylus of PHANTOM OMNI and move it using their arm as shown in figure 2.1. The objective of the game is to move from one panel to another without touching any walls that formed the maze. Touching the panels will reward points while touching the walls will minus points. Patients with severe impairment are suited for this exercise and for those with less severe injuries; the level of difficulty can be adjusted with the maze (Dreifaldt and Lövquist, 2006, p36).

2.2.2 Strengths

One of the strength of this game is that the level of difficulty can be varied greatly. Users can start with the easiest level which has only 2 panels without any walls. The difficulty can be varied easily because users can design their own maze automatically by typing the parameters into a text file which the program will read. The gradual increase in difficulty can give users a sense of accomplishment as they complete each level. This can motivate users to continue this exercise for a longer period of time. Furthermore, this game is easy to understand because the rule is simple.

2.2.3 Weaknesses

The biggest weakness of this game is that the game has some distractions. For example, the background shown in figure 2.1 is made up of five outer walls which can be simplified. In higher difficulty which involves many walls, it can be too difficult for the users to see paths between the walls. Stroke patients might experience attention problems when doing this exercise.

2.2.4 Recommendations

Firstly, the game can focus more on touch sensations. For example, the game can add areas with different smoothness to challenge users' control of their movements. The background can also be simpler, allowing the users to focus on the game easier. The objective need to be seen easily at all times.

2.3 Hidden Object

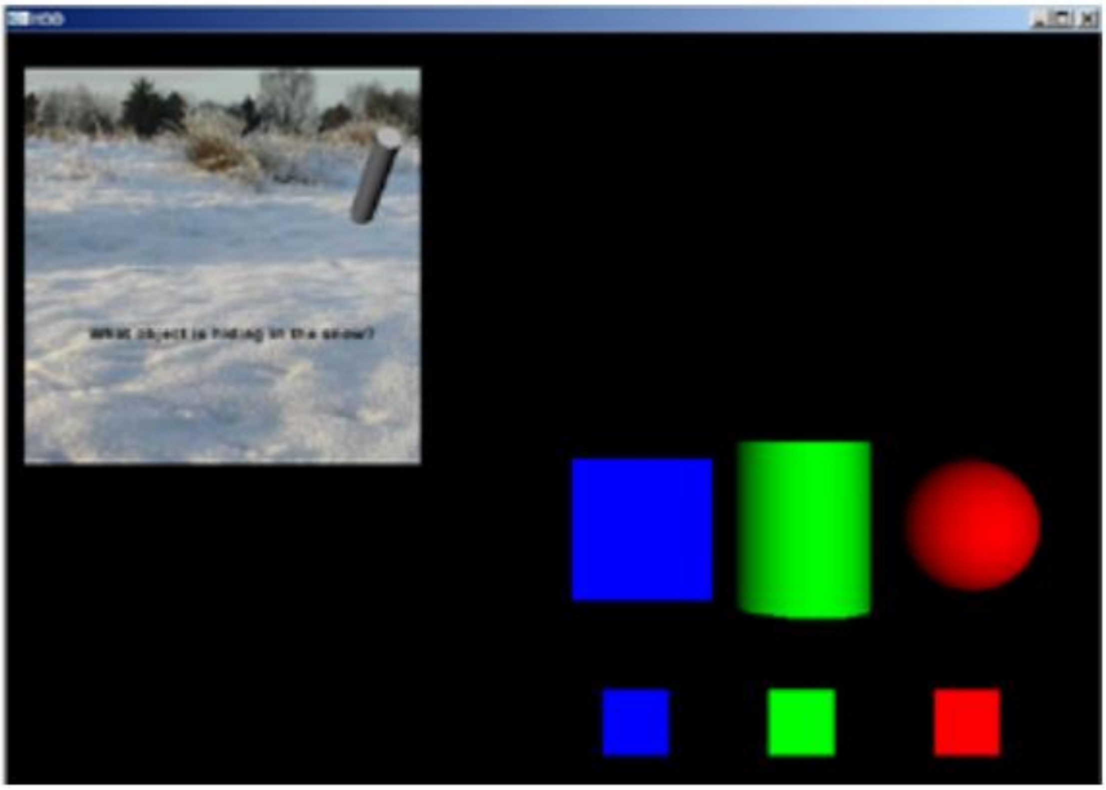

Figure 2.2 Hidden Object by Dreifaldt, U. and Lövquist, E. 2006

2.3.1 Overview

This game requires the user to grab the stylus and move both hand and arm. Finer manipulation of movements is needed. There is one object hidden in the snow and the user has to find out by feeling it through the snow. Bottom right of the screen shows three visible objects as a reference for user, as one of them is under the snow. The user can feel all three of them to make a comparison. Below the three reference objects are buttons for user to confirm which object is under the snow. Score is given based on time needed to find the correct object while user will get minus points if incorrect object is chosen.

2.3.2 Strengths

Finer sense of touch will be tested in this game. Users will have to rely on their sense of touch only to find out the correct object. The reference objects are also very useful for users to learn the touch of each shape. This game can be fun as well because it requires users to guess the hidden object.

2.3.3 Weaknesses

According to Dreifaldt, U. and Lövquist, E. (2006, p36), their volunteer reported that it is hard to distinguish objects even when simple objects such as cube, sphere and cylinder were used. This is because the pen from Phantom Omni is used to feel the objects instead of fingertips. Another reason is that vision helps greatly in recognising different kind of objects.

2.3.4 Recommendations

Additional characteristic of touch sensation can be added to help users distinguish each objects. Smoothness is an example of the characteristic that can be used. Big difference in smoothness can be a good hint for users to distinguish each objects.

2.4 Kinematic Assessment

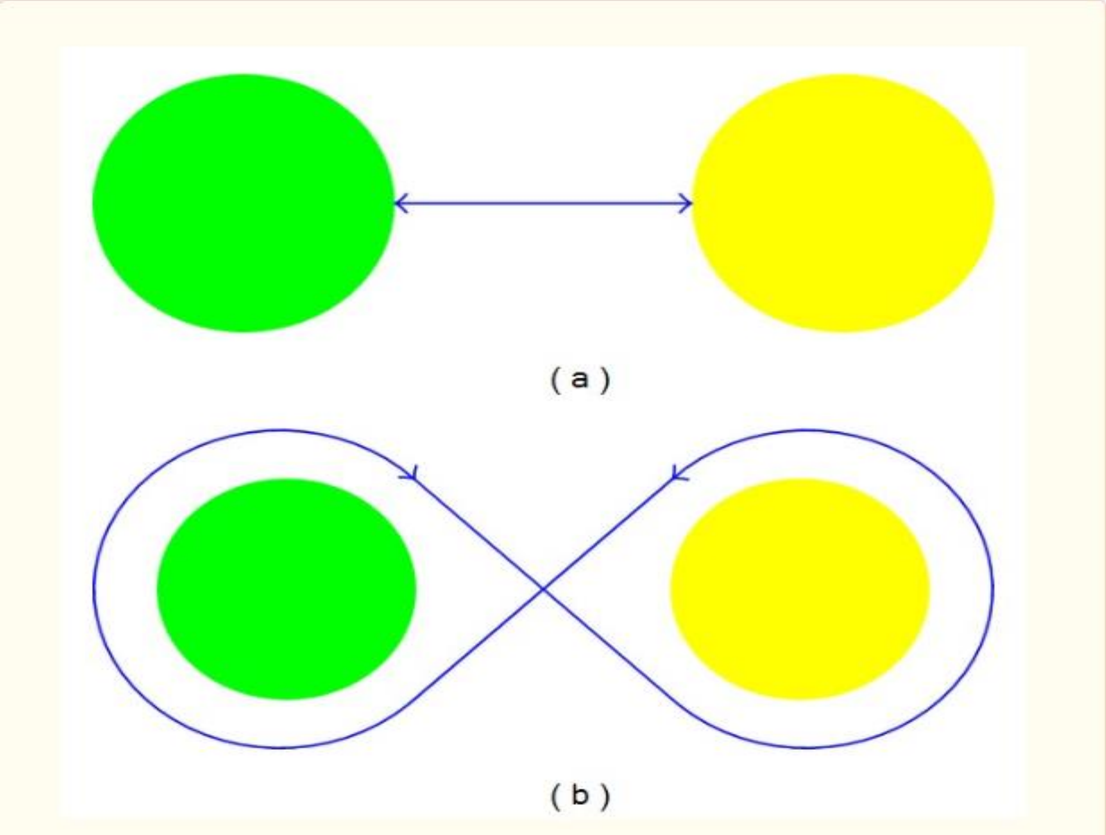

Figure 2.3 Kinematic Assessment by Turolla et al. (2013)

2.4.1 Overview

In the first task, the user is required to touch the inner surface of the circles alternatively for 10 times while trying to touch them using a shorter path. In the second task, the user is required to turn around the border of the circles while trying to draw the "8" as narrow as possible without touching the border of the circles. An illustration of both these tasks can be seen in figure 2.3 The performance is based on parameters such as average time needed to complete tasks, average velocity and average rate of change of acceleration in movements.

2.4.2 Strengths

Both tasks can be done in repetition for many times without requiring varieties in the tasks. The repetition helps users to improve their motor skill. The evaluation methods used are detailed which are great as indicators of how well the users have improved. Furthermore, the instructions for both of these tasks are simple and easy to understand.

2.4.3Weaknesses

However, the tasks above are lacking in terms of emphasising finer touch sensation in the motor-skill exercises. Motor skill exercises that has finer touch sensation might help stroke patients to recover at a better pace. Furthermore, the tasks are bland, not interesting and fun for users to repeat. Motivation might not be enough for some users to continue for a long period of time.

2.4.4 Recommendations

Adding additional touch sensation characteristic to the area around the circles can promote finer control of movement. For example, the area around the circles can have different level of smoothness to challenge the users' control of movement.

2.5 The Maze Exercise

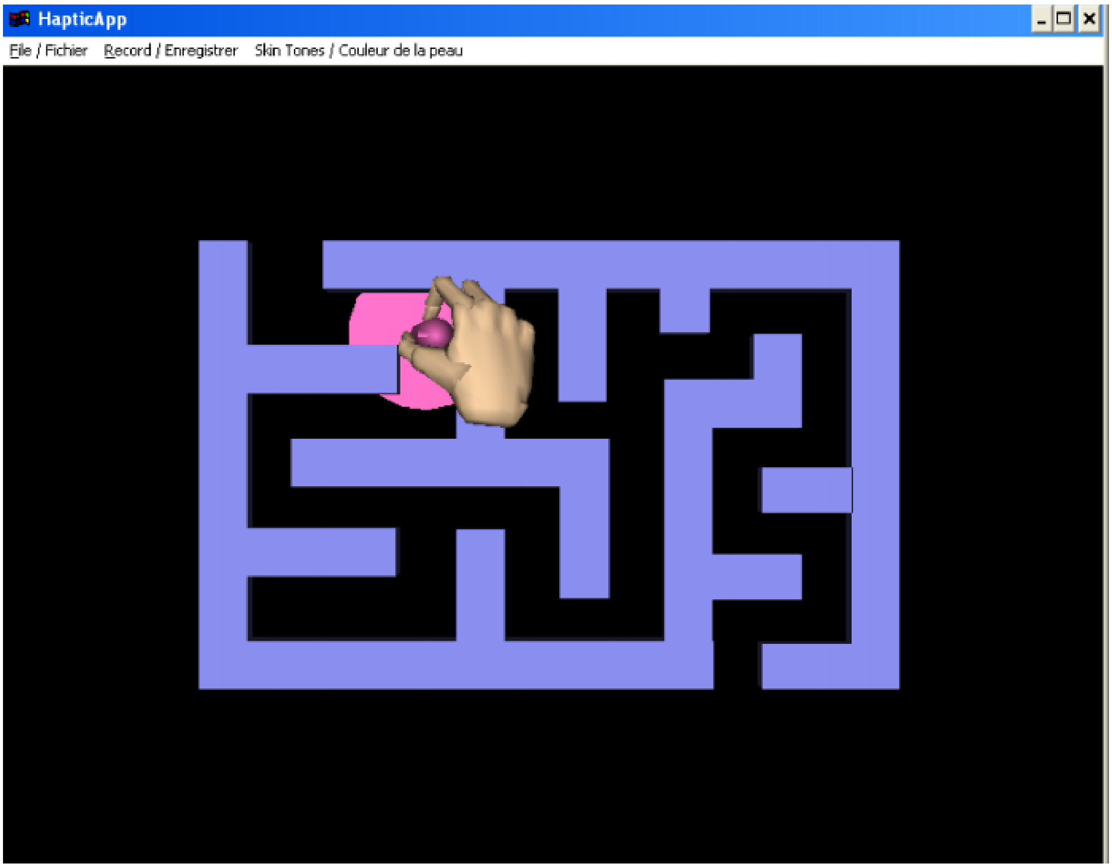

Figure 2.4 The Maze Exercise by Alamri et al. (2007)

2.5.1 Overview

This exercise require user to move the stick through the maze without touching the walls. This exercise aims to improve the motor skill and steadiness of hand of stroke patients. It has a simple design, only the maze and stick is shown. User can understand the exercise easily. This exercise will study the time needed to complete the exercise and number of collisions made by the user.

2.5.2 Strengths

The design is simple for user to understand and focus. The path between the starting point and ending point can be identified easily. User can do this exercise without unnecessary distractions. This exercise is interesting enough for user to do for a longer period of time.

2.5.3 Weaknesses

The exercise does not emphasise on touch sensation. User cannot regain sense of touch in an effective manner. Furthermore, the exercise does not show the number of collisions for user. User have to keep track of their collisions manually.

2.5.4 Recommendations

Additional touch sensation can be added along the path of the maze. Some paths can have different smoothness to challenge user. User will have to control their movements accordingly for different smoothness. Furthermore, information on current progress can be displayed.

2.6 Comparison of Strengths and Weaknesses

Applications	Strengths	Weaknesses
The Labyrinth	• Improve motor skill • Customisable difficulty • Progress tracking	• No finer sense of touch • Distractive background • Complicated paths for harder difficulty
Hidden Object	• Improve sense of touch	• Difficult to distinguish objects
Kinematic Assessment	• Improve motor skill • Simple and Easy	• No finer sense of touch required • Boring
The Maze Exercise	• Improve motor skill • Simple Design	• No finer sense of touch • No progress tracking

Table 2.1 Comparison of reviewed applications

The Labyrinth, Kinematic Assessment and The Maze Exercise primarily help stroke patients to improve motor skill while Hidden object primarily help stroke patients to improve sense of touch. The Labyrinth has a sophisticated design while The Maze Exercise has a simpler design. Kinematic Assessment is the easiest exercise to understand out of all reviewed applications. Hidden Object is different from other reviewed application; users rely mostly on touch sensation to complete.

Chapter 3: Methodology

3.1 Methodology

The chosen software methodology is prototyping. A prototype will be developed by gathering feedback from stroke patients and experts. Stroke patients with enough grip strength can try the prototype before the final design is decided. The feedbacks will be analysed to refine the prototype. The data will be stored in supervisor's office and disposed through paper shredding after completion of project. This methodology can help ensure the final application will be as effective as possible.

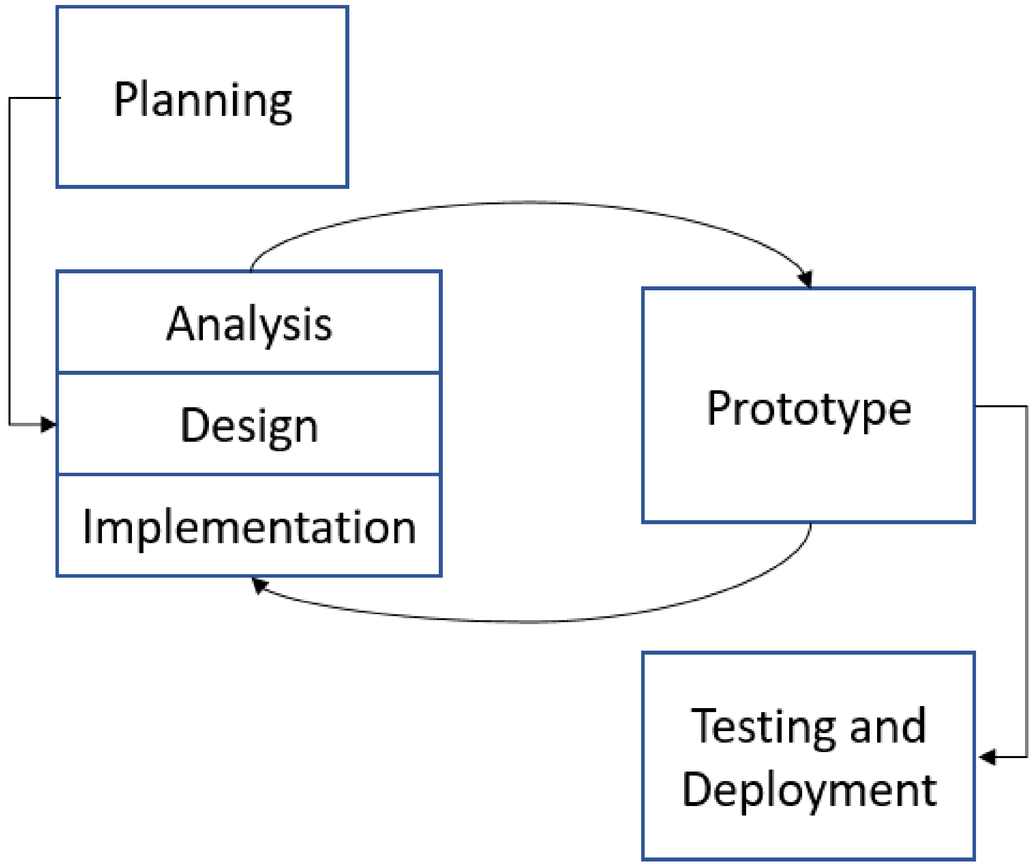

Figure 3.1 Prototype Methodology

Planning Phase

During this phase, the project title is determined. Information about stroke and rehabilitation exercises are gathered. Challenges and problems in existing technological based application are identified.

Analysis, Design, Implementation Phase

During this phase, existing technological based application and their research papers will be studied. Their strengths and weakness provide information to propose a better solution. The research papers also provide explanation on the challenges and problems faced by the authors. Furthermore, requirements will be gathered from stroke patients and experts through interviews. There will be multiple visits to Yayasan Ipoh and National Stroke Association of Malaysia (NASAM). Important and useful characteristics of the exercises regularly done by stroke patients also will be analysed.

Prototyping Phase

During this phase, the design of the proposed solution will be worked on. A prototype will be tested to make sure it is easy to use. Then, the prototype will be worked on for improvements.

Testing and Deployment Phase

During this phase, the final application is produced and ready for testing and deployment. Stroke patients will test this application to find out its effectiveness in helping stroke patients to rehabilitate.

Date	Purpose
29/1/2020 – 14/2/2020	Interviewing stroke patients and experts to gather requirements.
13/7/2020 -31/7/2020	Test the final application with stroke patients to determine its effectiveness.

Table 3.1 Visitation Schedule

Chapter 4: Preliminary Result and System Design

4.1 Results of Interview

A therapist from Yayasan Ipoh and 2 therapists from National Stroke Association of Malaysia (NASAM) are interviewed. The therapist from Yayasan Ipoh has at least 3 years of experience as a therapist and is treating around 20 patients on a weekly basis. A therapist from National Stroke Association of Malaysia(NASAM) has 3 years of experience and treat around 30 patients weekly in group sessions. Another therapist has 5 years of experience and treat around 10 patients weekly in one on one sessions. In depth information about stroke patients are gathered.

The therapists mentioned that the conditions of every stroke patient can vary. Some stroke patients can lose most of their strength and sensations on the affected side and each stroke patient varies greatly in time needed to recover. The therapists mentioned that 3 to 6 months after the stroke is the most crucial time for therapy because therapies are the most effective during this period. After that period, chances for significant recovery are unlikely. So, therapists might recommend exercises that help patients to use their unaffected side to compensate for the affected. Besides that, therapies are recommended to be continued after this critical window of recovery to maintain their recovery.

Based on the interviews from therapists, here are a few elements that can help make the rehabilitation exercises effective:

Elements	Description
Task Specific Activities	Stroke patients are more motivated to do the exercises if the activities resemble daily activities. Stroke patients are more likely to exercise on their own if they can see that the exercises can have direct positive impact.
Intense and Repetitive	The rehabilitation exercises need to be repeated many times by the stroke patients intensively to regain their motor control. These exercises will help to re-establish communication between the damaged parts of the brain and body.
Game-like Exercises	One problem that stop stroke patients from actively exercising is loss of motivation. Game-like exercises can motivate the stroke patients to engage in exercises for a long period of time. Stroke patients will challenge themselves to do better which in turn will improve their condition.

Table 4.1 Effective elements of rehabilitation exercises

The therapists mentioned that there are several ways to determine the stages of stroke recovery. One of it is the Brunnstorm Approach which was developed by a Swedish physical therapist named Signe Brunnstorm in the 1960's (Brunnstorm, 1970). This approach focus on synergic pattern of muscle movements. There are 7 stages of recovery proposed in this approach, which are shown in a table below:

Stages	Description
Stage 1: Flaccidity	• Flaccid muscles, no voluntary movement on the affected side • Muscles unable to receive signal from the brain due to nerve damage
Stage 2: Spasticity Appears	• Basic limb synergies redevelop • Muscles might have small, spastic and abnormal movements
Stage 3: Increased Spasticity	• Spasticity is at its peak (muscle stiffness) • Inability to restrict the brain's motor neurons causes muscle to involuntarily contracts • Minimal voluntary movements
Stage 4: Decreased Spasticity	• Spasticity in muscles start to decline • Regain control mostly in extremities • Movements may be out of sync
Stage 5: Complex Movement Combinations	• Spasticity in muscles continues to decline • Muscles are more coordinated • Voluntary movements can be more complex • Abnormal movements decline dramatically but some movements may still appear
Stage 6: Spasticity disappears	• Spasticity in muscles completely disappears • Motor control is almost fully restored • Synergy patterns are more coordinated
Stage 7: Normal Function Return	• Fully regained function in affected areas • Able to move muscles in controlled and voluntary manner

Table 4.2 Stages of Stroke in Brunnstorm Approach (Saebo, 2018)

Besides the Brunnstorm Approach, Manual Muscle Testing Grading System (MMT) and Motor Assessment Scale (MAS) can also be used to measure the state of recovery of stroke patients. Manual Muscle Testing Grading System is used to test isolated patterns of movement for body parts such as extension and flexion of body parts while Motor Assessment Scale is used to test movements that are more complex and resemble closer to tasks.

There are 8 sections in Motor Assessment Scale, namely (i)supine to side-lying onto intact side which is mainly about trying to roll to intact side from supine, (ii)supine to sitting over side of bed which is mainly about trying to move from supine to sitting, (iii)balance sitting which is mainly about sitting on a stool with balance, (iv)sitting to standing which is mainly about ability to change from sitting to standing, (v)walking which is mainly about walking with ease, (vi)upper arm function which is mainly about movements of shoulders and elbows, (vii)hand movements which is mainly about movement wrists and grip strength and finally (viii)advanced hand activities which is about completing complicated tasks with hands. There are 6 activities in each section to assess their performance in this section.

Grade		Function of Muscle
0	None	No contractions in muscle felt or seen
1	Trace	Contractions in muscle felt or seen but has no motion
2	Poor	Full range of motion with gravity eliminated (moves in horizontal plane)
3	Fair	Full range of motion against gravity without added resistance
4	Good	Full range of motion against gravity along with moderate resistance
5	Normal	Full range of motion against gravity along with strong resistance

Table 4.3 Manual Muscle Testing Grading System

(Amended from ScottSevinsky, n.d.)

There are many exercises that patients can do to improve their condition. For this project, exercises that improve motor skills of hand and forearm will be emphasised. The therapists mentioned that there are several exercises that can help improve the motor skills of hand and forearm, some examples are shown in a table below:

Exercises	Motor Skills Involved
Grabbing a cup	• Fingers flexion (holding cup) • Fingers extension (releasing cup) • Elbow flexion (lifting cup) • Elbow extension (putting down cup)
Pegboard (Stroke patients have to put all the pegs into a board and then take them all out from the board to put into their respective cups according to the colour. The shorter time needed to finish the better)	• Opposition of index finger and thumb (holding pegs) • Wrist flexion and extension (lifting and putting down pegs) • Elbow flexion and extension (reaching in and out)
Drawing straight lines on a paper	• Opposition of index finger and thumb (holding pencil) • Wrist flexion (holding pencil down against paper) • Elbow flexion and extension (drawing lines)
Bending wrist	• Wrist flexion (against gravity if palm faces up, not against gravity if palm faces down) • Wrist extension (against gravity if palm faces down, not against gravity if palm faces up)

Table 4.4 Examples of hand and forearm exercises

In order to participate in this research, stroke patients should at least be in grade 2 from Manual Muscle Testing Grading System because the stroke patients are required to have some degree of control over their muscles to operate Phantom Omni.

4.2 Proposed Method

After gathering requirements, these are the characteristics that the proposed solution should have in order to be useful in helping stroke patients:

Easy to Use:
Stroke patients might face cognitive impairment, so it is important for the system to be easy to use. The user interface design should be easy to learn and does not require them to constantly memorize the steps.

Useful exercise design:
The exercise design should be useful in helping stroke patients to improve their condition. The exercise also has to be intensive and repetitive.

Simple and Attractive exercise design:
Exercises have to be done for a long period to improve stroke patients' condition, so an attractive exercise design is crucial to motivate stroke patients to continuously exercise. A simple design will also allow stroke patients to focus better.

Performance Assessment:
It is important to know the progress stroke patients are making so the system should provide information regarding their performance.

Besides these characteristic mentioned above, the proposed prototype has these elements of a computer application:

- Text
- Graphics
- Force Feedback
- Animation

Proposed prototype requirements:

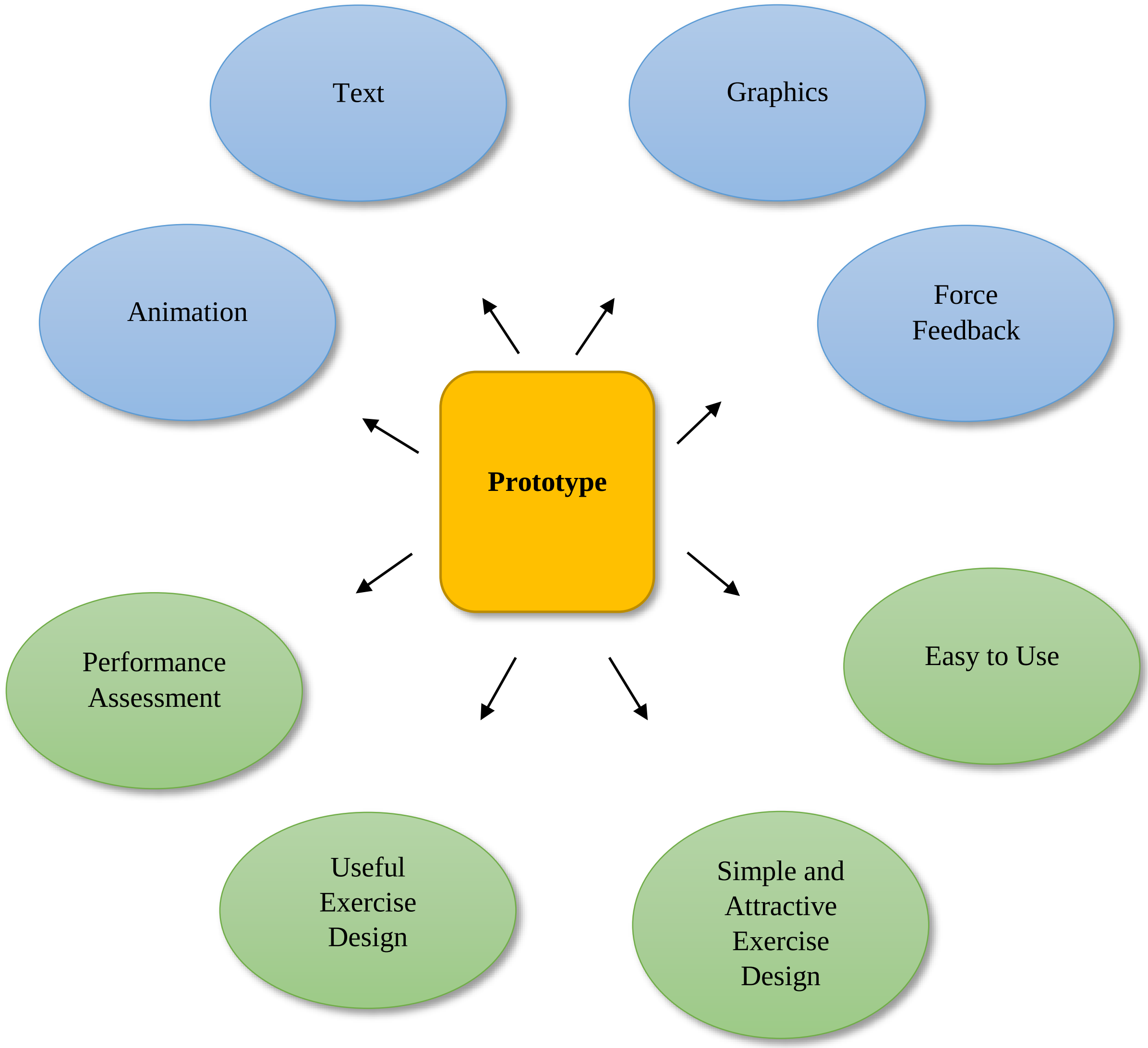

Figure 4.1 Proposed Prototype Requirements

Interface Design

Shared functionalities

All the exercises have 4 buttons shown at the top of the screen. The first button is the "Pause" button which when pressed pauses the time and show another interface that allows user to modify the values of constant force and depthness (if applicable). The second button is the "Clear" button, which when pressed clears all the statistics and lines (if there is any) and reset time. The third button is the "Screenshot" button which when pressed screenshot the screen of the exercise and save it in "Screenshot" folder in the directory of the application. The fourth button is the "Statistics" button which when pressed will toggle on or off the texts of statistics.

Figure 4.2 Buttons for shared functionalities

Exercise 1: Straight Lines Drawing

Below is an interface design of an exercise that let stroke patients to draw straight lines. The stroke patients have to draw a straight line from the stand to the end of each black box while the red box applies the constant force of haptic effect that pushes the stylus back into drawing area if stroke patients move out it. The stylus speed bar at bottom right shows the speed of the stylus while the depth meter shows how hard the stylus is pressing against grey board in the background. Lines are drawn when stylus is pushed against the grey board similarly to how a pen draw lines. Basic analytics implemented are depth success rate, depth standard deviation, speed standard deviation, average depth and average speed. These analytics will only be recorded when the stylus is touching in the drawing area between the red bars. In the pause menu, user can change the depthness required to draw line and the level of constant force through sliders or input fields.

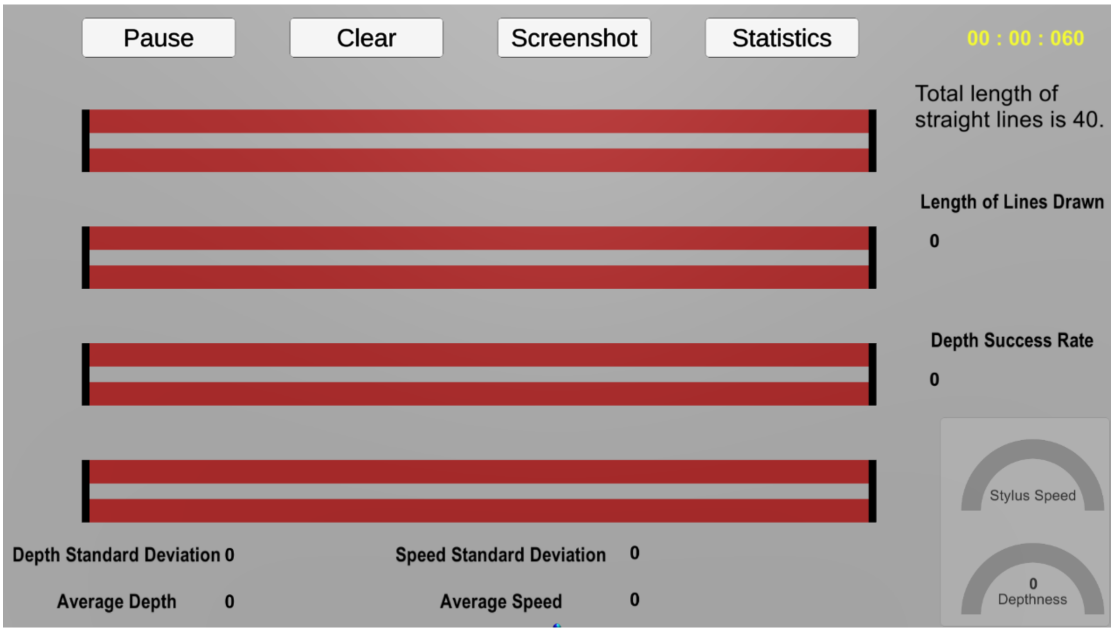

Figure 4.3 Exercise 1 Interface Design

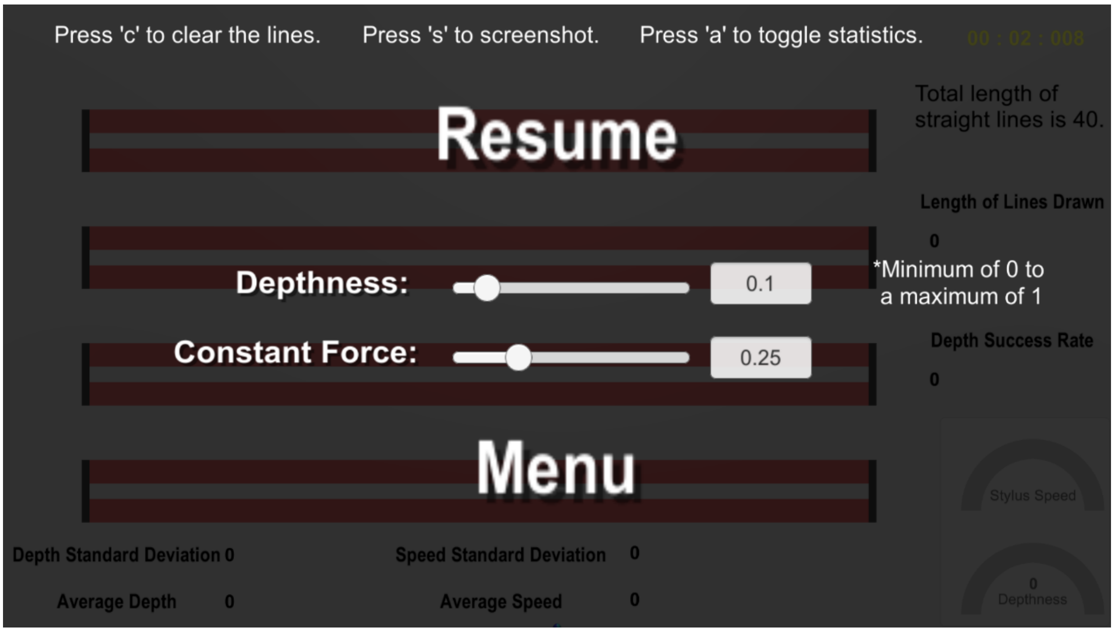

Figure 4.4 Exercise 1 Pause Menu

This exercise aims to improve several motor skills. Firstly, opposition of thumb and index finger can be trained when stroke patients are holding the stylus to draw the line. Secondly, wrist flexion can be trained when stroke patients are holding the stylus against the grey board in the background to draw the line. Different levels of depth required to draw the line can be set to raise the intensity of the exercise. Lastly, elbow flexion and extension can be trained when stroke patients move the stylus across the black box. Beside motor skills, hand-eye coordination and muscle strength control are tested too.

Exercise 2: Spiral Lines Drawing

Below is an interface design of the second exercise that let stroke patients to draw spiral lines. This exercise is similar to the first exercise but it is more advanced because spiral lines are harder to draw. Similarly, the spiral models have constant force of haptic effect that pushes the stylus back into the black box if stroke patients touch it. The spiral on the left is for drawing in the direction of counter clockwise while the right spiral is for clockwise. The implemented analytics are the same as exercise 1 and are only recorded in and around the area of the spiral model. The pause menu has a similar design as exercise 1 where depthness and constant force can be changed through sliders and input fields.

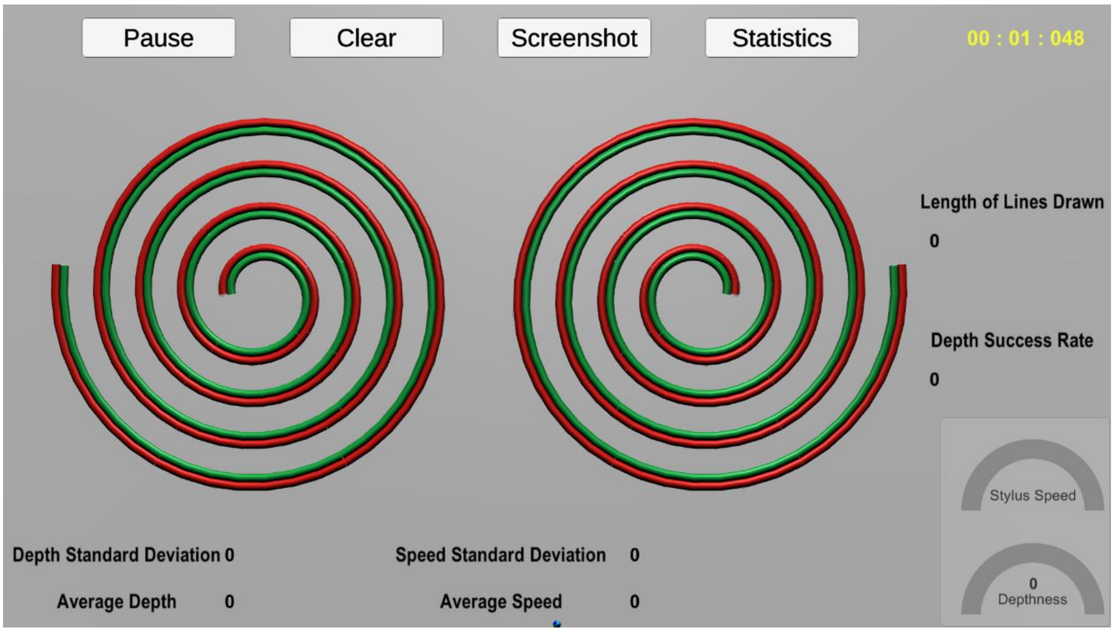

Figure 4.5 Exercise 2 Interface Design

This exercise aims to improve the same set of motor skills in the first exercise. This exercise is suitable for stroke patients who want train on a more advanced scale. Hand-eye coordination and muscle strength control are the skills that are trained and tested heavily.

<u>Exercise 3: Wrist Strength</u>

Below is another interface design of an exercise that trains the wrist flexion and extension of stroke patients. There are 2 versions of this exercise. In the first version, there are 2 different bar for stroke patients to choose, one is against gravity and another is not. Stroke patients have to move their stylus from the start area to the end of the bar with each colour representing different strength of constant force of haptic effect that pushes the stylus toward the start area. Yellow colour represents the weakest constant force followed by orange and lastly red colour as the strongest constant force. The highest force going up or down is recorded automatically when the stylus is near the end of each bar. In the pause menu, user can change the constant force for each bar by typing in the input field beside them.

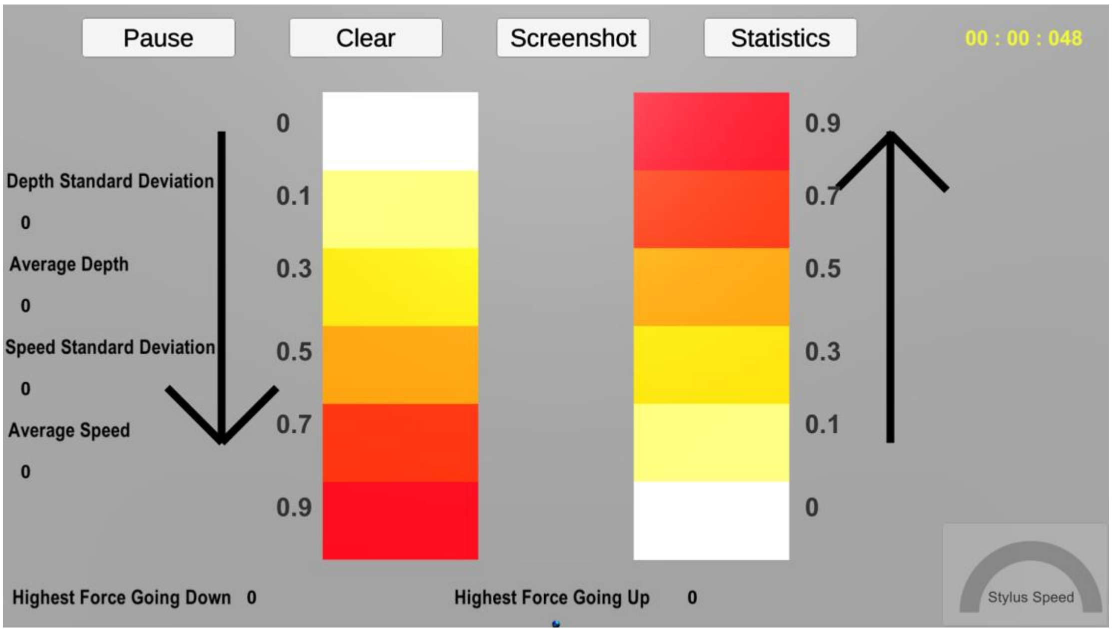

Figure 4.6 Exercise 3 Interface Design

Figure 4.7 Exercise 3 Pause Menu

Exercise 4: Wrist Strength (Version 2)

Below is the second version. In this version, there is only 1 bar that is going against gravity. The original is modified because the first testing caused some issues to the device and also it is found that going along gravity is easy for stroke patients who can grip the stylus.

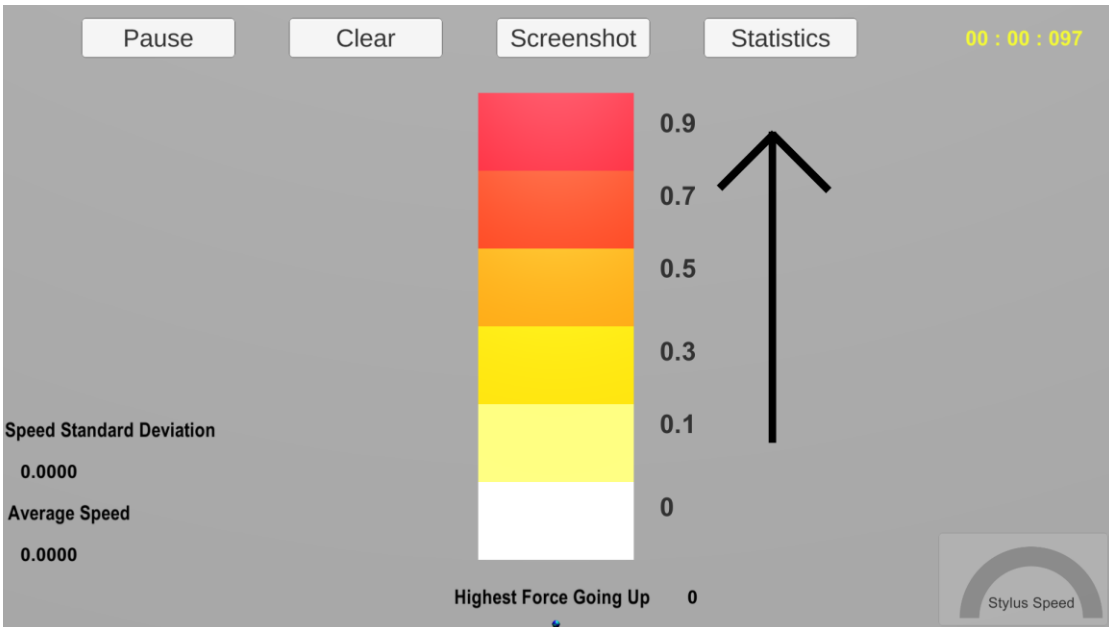

Figure 4.8 Exercise 4 Interface Design

Both of exercise 3 and 4 aims to improve strength of wrist flexion and extension. Stroke patients can choose to train their wrist against or not against the gravity. Stroke patients can assess the strength of their wrist according to the colour they can challenge. Opposition of index finger and thumb is also trained because stroke patients will be holding the stylus.

System Design/Overview

Phantom Omni is a hardware device that can allow user to feel virtual objects by applying force-feedback on the user's hand through the stylus on the device. This device can simulate touch sensations in the exercises for stroke patients. Examples of haptic effect this device can provide are vibration, friction and spring. The required drivers and plugin for Unity game engine is provided by the company (3D Systems). The plugin included scripts for haptic effects to be used in Unity. Unity is the platform used to develop the 3D environment for the stroke exercises. The stroke patients will do the exercises through this 3D environment.

Unity game engine is chosen because it supports integrating the haptic device with Unity for development. Furthermore, Unity has strong physics engines that allows the 3D environment to be realistic enough. User interfaces can be designed in a fast and intuitive manner with the tools provided. Blender is also used to create models that can be exported to Unity game engine. This is because models made in Blender can be exported to Unity easily. The spiral model is created using Blender. Microsoft Visual Studio 2017 is used to code the scripts in C# for Unity.

4.3 Implementation Issues and Challenges

There are a few implementation issues and challenges when developing this application. First, there are limited information regarding the development of application using this haptic device on Unity. Most information can only be obtained through the documentation of official haptic plugin from 3D Systems.

Secondly, designing applications that are interesting and allow stroke patients to use it without constant supervision are difficult. Many factors have to be considered. Many stroke patients are unmotivated to continue rehabilitation exercise and are generally unhappy about their condition. Applications that are fun and effective are not easy to be designed.

4.4 Timeline

	Task	Start Date	End Date	Duration (days)
	Final Year Project 1			
1	Study Project Background	13/01/2020	18/01/2020	6
2	Literature Review	19/01/2020	28/01/2020	10
3	Interviews and Observations	29/01/2020	14/02/2020	17
4	Requirements Analysis	15/02/2020	21/02/2020	7
5	Design Prototype	22/02/2020	26/02/2020	5
6	Prototyping	27/02/2020	27/03/2020	30
7	Finalise Documentation	28/03/2020	03/04/2020	7

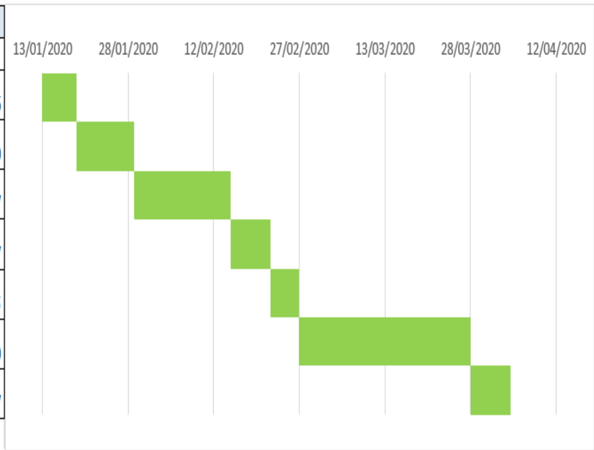

Figure 4.4 Gantt Chart for FYP 1

	Task	Start Date	End Date	Duration (days)
	Final Year Project 2			
1	Prototype improvements	01/06/2020	21/06/2020	21
2	Implementation	22/06/2020	05/08/2020	45
3	Documentation	06/08/2020	27/08/2020	22

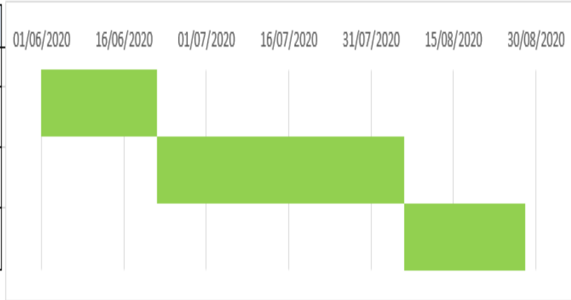

Figure 4.5 Gantt Chart for FYP 2

Chapter 5: Testing

5.1 Testing Setup and Results

A stroke patient from Yayasan Ipoh has tested Exercise 1, 2 and 3 in one sitting. A laptop and Phantom Omni are used to conduct the test. She had a mild stroke and has been seeking physiotherapy for close to 2 years. Her right hand is affected by stroke and this hand is used to participate in this test. This testing is done by recording the results of the first try and second try. Results of the first and second try are then compared.

For each try of exercise 1 and 2, time to complete the exercises are recorded. For each try of exercise 3, she has 1-minute maximum to reach the highest level for each side and time used to complete it will be recorded if she finished it before the maximum time. She tried exercise 1, 2 and 3 consecutively on the first try. Between the first try and second try, there is a 15-minute period of time that she can train and rest. After the 15-minute period of time, she tried exercise 1, 2 and 3 consecutively for the second try. This method is chosen to find out if this approach can improve motor skills and sense of touch of stroke patients after training with the exercises for a period of time.

A therapist from Yayasan Ipoh suggested that the depthness of exercises to be 0.1 because it is close to the minimal force of Manual Muscle Testing Grading System (MMT). Some basic statistics are recorded to provide more insight. For example, length of lines drawn is used to give an idea of how neat the lines drawn is. A straight line between 2 points are the shortest. The units used for depthness and stylus speed in the records are based on the OpenHaptics Plugin for Unity while others are based on Unity.

Exercise 1: Straight Lines

	Time (Minute: Second)	Length of Lines Drawn	Average Stylus Speed	Stylus Speed Standard Deviation	Average Depth	Depth Standard Deviation
First Try	2:58	57.75433	1.2595	0.0149	22.8266	0.1638
Second try	1:06	45.69627	1.4954	0.0167	61.2567	0.3594

Table 5.1 Exercise 1 Results

Exercise 2: Spiral Lines

	Time (Minute: Second)	Length of Lines Drawn	Average Stylus Speed	Stylus Speed Standard Deviation	Average Depth	Depth Standard Deviation
First Try	3:30	91.4852	1.4807	0.174	16.0141	0.0970
Second try	1:56	55.00941	1.2393	0.0089	29.0069	0.1219

Table 5.2 Exercise 2 Results

Exercise 3: Wrist Strength (Version 1)

	Going Along Gravity (Wrist Flexion only)		Going Against Gravity (Wrist Extension only)	
	Time (Seconds)	Highest Force	Time (Seconds)	Highest Force
First Try	30	0.9	28	0.9
Second Try	5	0.9	6	0.9

Table 5.3 Exercise 3 Results

For the second testing, another 5 stroke patients from Yayasan Ipoh have tested Wrist Strength Version 2. A laptop and Phantom Omni are also used for this testing session. Below are the details of the 5 stroke patients:

Patient Number	Age	Total time seeking therapies	Stroke affected hand
1	75	2.5 years	Right hand
2	77	3 months	Left hand
3	74	1 month	Left hand
4	20	1 year	Right hand
5	80	2 years	Right hand

Table 5.4 Details of Patients for Second Testing Session

The stroke patients will use their stroke affected hand to participate in the test. The original testing session is modified because the haptic device no longer displays accurate stylus position especially the z-axis to the laptop after the first testing. The haptic device cannot be used to test for depthness in exercise 1 and 2. It is also because that going along gravity is not that necessary to be tested because it is easy for stroke patients who can grip the stylus. So, exercise 4 is used for the second testing session.

Similar to the first testing session, results of first and second try are recorded and compared. For each try, there is 1 minute for them to reach the final level. The stroke patients will be tested on wrist extension and wrist flexion consecutively on the first try. Between the first try and second try, there is a 3-minute period of time that they can train and rest. After the 3-minute period of time, the stroke patients will be tested on wrist extension and wrist flexion consecutively on the second try. This testing is conducted to find out if the exercise can improve wrist strength of stroke patients after training with the exercise for a period of time.

Exercise 4: Wrist Strength (Version 2)

		Wrist Extension		Wrist Flexion	
Patient Number		Time (Seconds)	Highest Force	Time (Seconds)	Highest Force
1	First Try	3	0.9	21	0.9
	Second Try	6	0.9	3	0.9
2	First Try	32	0.9	6	0.9
	Second Try	43	0.9	21	0.9
3	First Try	10	0.9	43	0.9
	Second Try	14	0.9	11	0.9
4	First Try	5	0.9	6	0.9
	Second Try	3	0.9	2	0.9
5	First Try	36	0.9	6	0.9
	Second Try	9	0.9	4	0.9

Table 5.5 Exercise 4 Results

5.2 Result Analysis

The results show that she improved in all exercises on the second try. The lines she drawn on the second try for both exercise 1 and 2 have improved greatly after a few tries. The lines are neater as shown in the decrease in length of lines drawn and she does not go out of bound as much. The increase in depth success rate might suggest that she improved her strength and control. On the second try of exercise 3, she reached to the end for each side in a single push. After the testing, she commented that she does not feel used to it. It probably felt new drawing lines in the air.

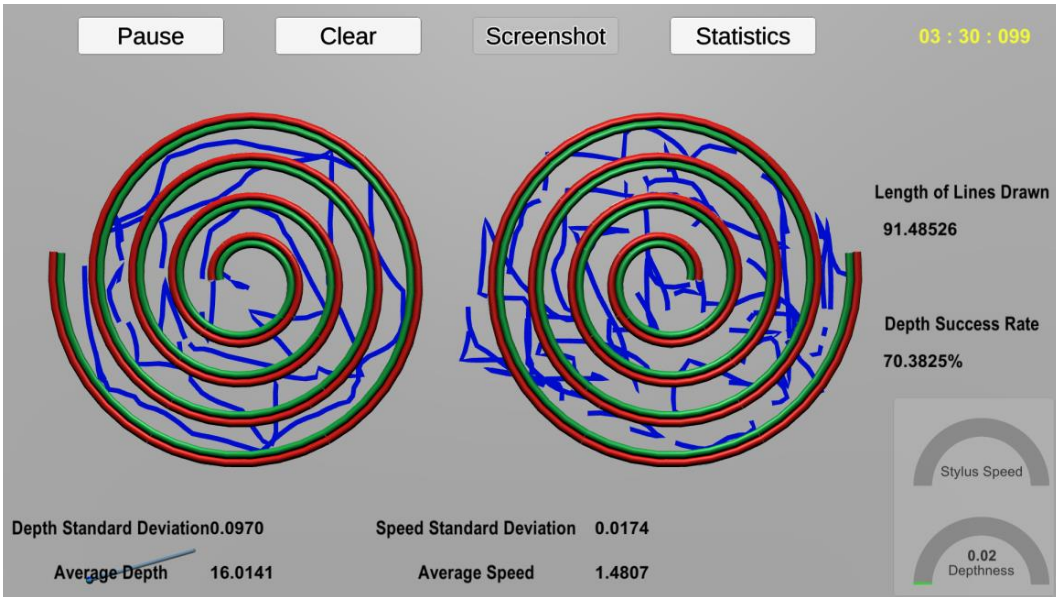

Figure 5.1 Exercise 2 First Try Screenshot

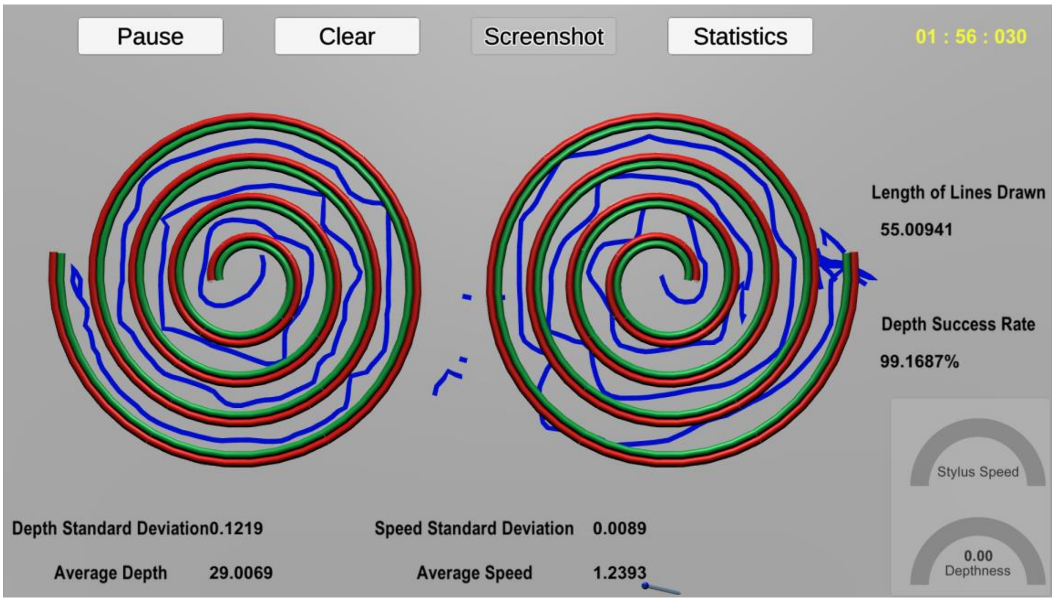

Figure 5.2 Exercise 2 Second Try Screenshot

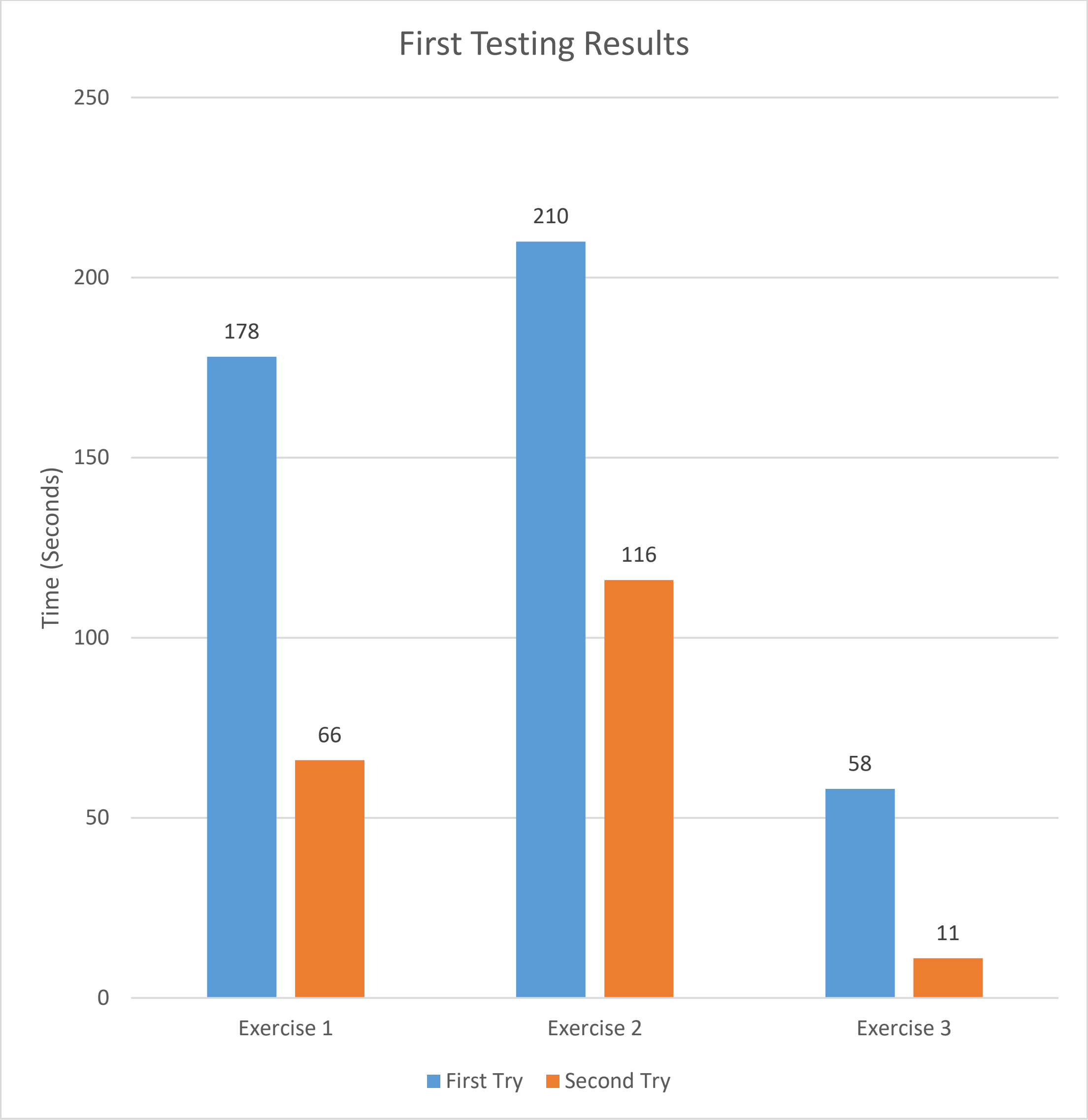

Figure 5.3 First Testing Results

For the second testing, a few patients have small problem of finding out how to grip the stylus. It might be because the stylus being bigger than a typical pen and the stylus is being attached to the device. The reason patient number 2 took more time on the second try is because patient number 2 met some difficulties staying within the box areas while pushing up. Patients who tried to reach to the top in a single big push need lesser time than those who push to the top gradually. This may be because by pushing to the top gradually, patients find it harder to stay within box because of the constant force. All 5 patients managed to reach the final level. It seems that the levels of constant force used do not pose a big challenge for patients who can grip the stylus.

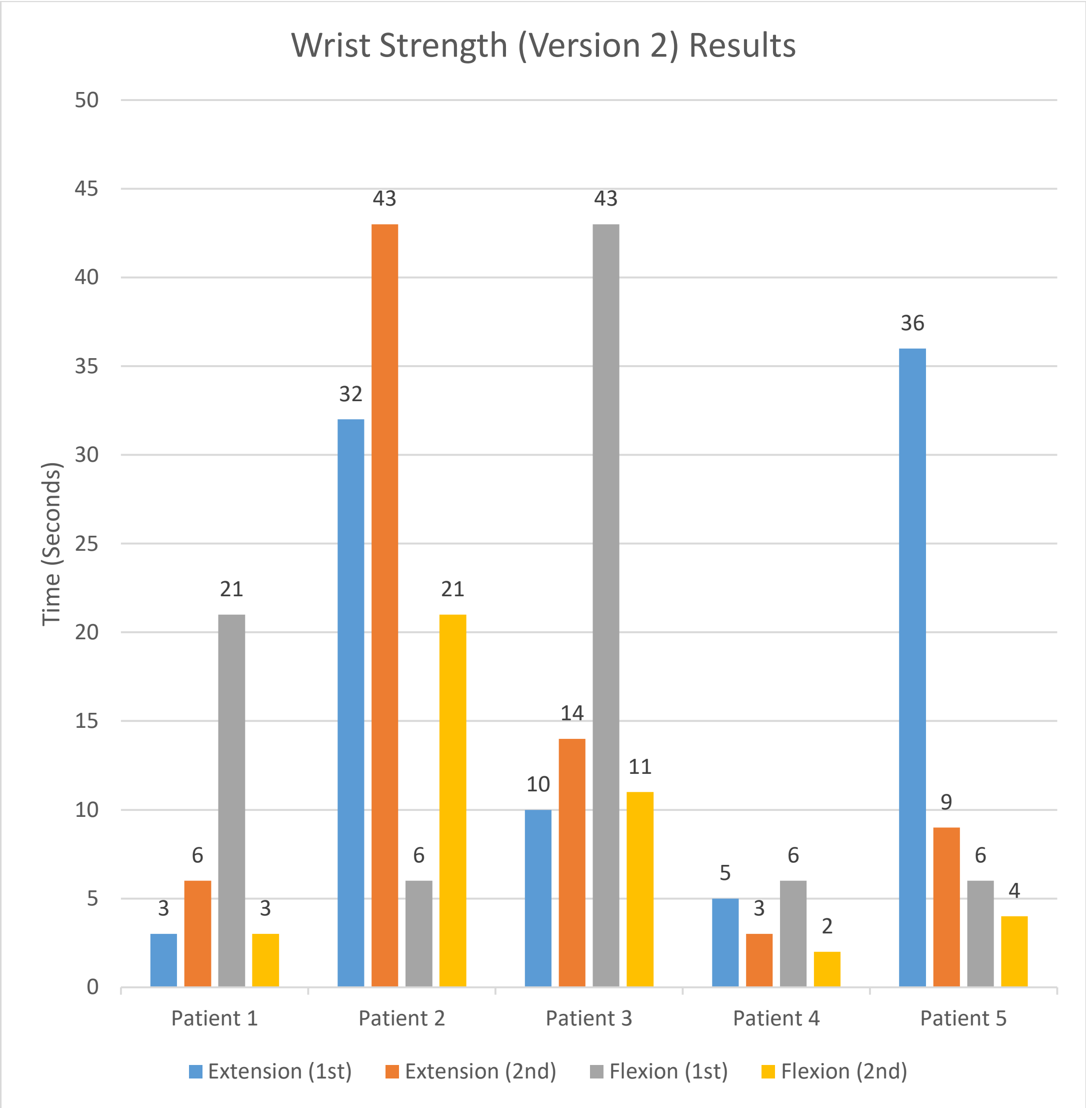

Figure 5.4 Second Testing Results

5.3 Challenges and Limitations

There are several challenges and limitations encountered during the testing. When the first patient was testing it, an issue appeared near the end of the second try. The computer can no longer display the position of the stylus correctly especially the z-axis in the exercises. One possible cause is pushing the stylus hard enough against the board while applying constant force for a period of time. The second issue is that the haptic device can only be used by stroke patients who have enough grip strength which is mentioned by the therapists. This means that not all stroke patients are suitable for this kind of approach. The therapists suggested bandaging hands with the stylus for stroke patients if they do not have enough grip strength. The third issue is that the haptic device has a limited range of motion to allow for exercises that require more space.

Chapter 6: Conclusion

6.1 Discussion and Project Review

Besides the improvement of most stroke patients in their second try, some of the stroke patients mentioned that using haptic device is a fresh approach that they need time to get used to. Most stroke patients felt difficult to handle the haptic device at first, but some of them felt happy and confident when they can just push through the bars in exercise 4 within a short amount of time for their second try.

	Percentage Change	
	Time	Length of Lines Drawn
Exercise 1	-62.92%	-20.88%
Exercise 2	-44.76%	-39.87%
Exercise 3	-81.03%	-

Table 6.1 First Testing Session's Result Changes

	Percentage Change of Time	
Patient Number	Wrist Extension	Wrist Flexion
1	+100%	-85.71%
2	+34.38%	+250%
3	+40%	-74.42%
4	-40%	-66.67*
5	-75%	-33.33%

Table 6.2 Second Testing Session's Result Changes

The proposed elements are implemented to a certain extent. Some of the elements have room for improvements.

Elements	Achievement
Easy to Use	Yes
Useful exercise design	Yes
Simple and Attractive exercise design	Yes
Performance Assessment	Yes
Text	Yes
Graphics	Yes
Force Feedback	Yes
Animation	Yes

Table 6.3 Proposed Prototype Requirements Achievements

This project implemented technological based applications that incorporates motor sensory elements and basic analytics to help improve motor skills and sense of touch of stroke patients. Motor sensory elements can provide a new element in exercises that can help stroke patients recover. Technological applications also have the advantage of automatic data recording for storage and analytics when compared to traditional methods.

It is unfortunate that the haptic device met some issues during testing. However, the results showed that there is a possibility that this approach can help improve motor skills and sense of touch of stroke patients. Technological based applications that incorporates motor sensory elements are an uncommon approach that may require some time for stroke patients to get used to it. It can be used to provide variability in therapies that can help stroke patients to be interested in continuing therapies for a long period of time. Moreover, the basic analytics implemented can provide insight on the progress stroke patients are making. It can be used for evaluations purposes besides therapies. Recording analytics allow therapists to review at a later date. Stroke patients can train at home without constant attention by both patients and therapists to take note of their progress.

6.2 Future work

Research on suitable levels of constant force to help stroke patients drawing lines can be done. Furthermore, stronger constant force in wrist strength exercise can be implemented to test the stroke patients. Other haptic effects and other designs can also be explored to help stroke patients improve. More features such as managing records and sophisticated analytics can be implemented to help analyse progress.

6.3 Summary

In summary, a technological based application that incorporates motor sensory elements is designed to help improve motor skills of stroke patients. The constant force in the proposed solution is used to guide stroke patients in doing exercises and improve their wrist strength. The emphasis on motor sensory elements is an improvement on reviewed existed technological applications that do not emphasise on the use of motor sensory elements to enhance the exercises for stroke patients. Furthermore, basic analytics are also implemented to provide insight. The testing showed that there is a possibility that this approach can be beneficial. An effective solution for stroke patients to regain motor skills is needed because they need strong motor skills to be independent in their lives.

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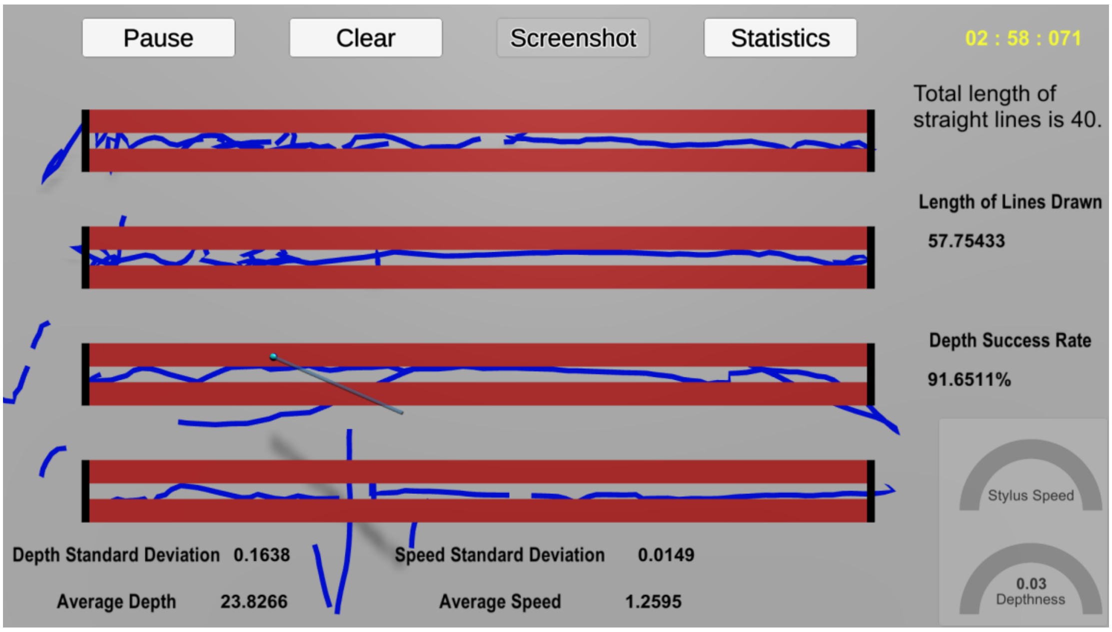
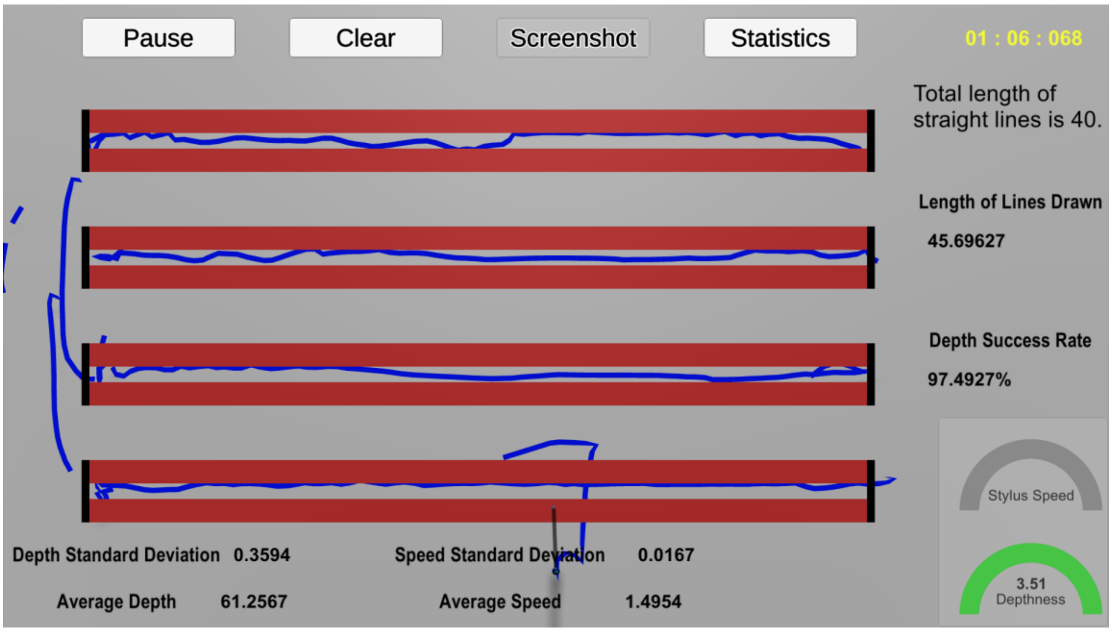
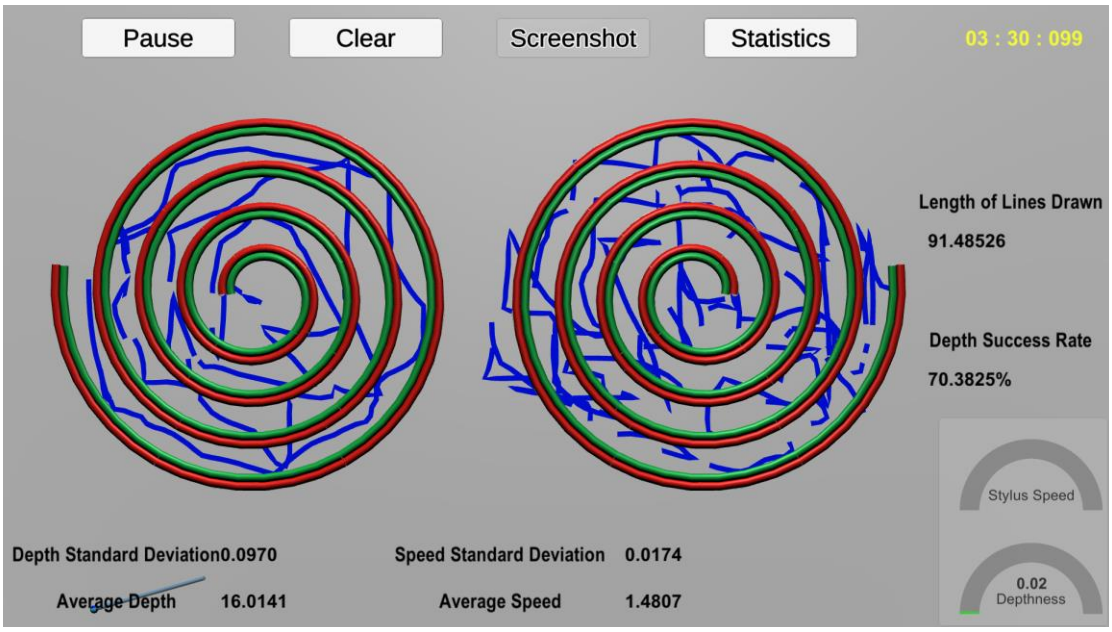
APPENDIX A: Testing Results Screenshots



A.1 Exercise 1 First Try Screenshot



A.2 Exercise 1 Second Try Screenshot



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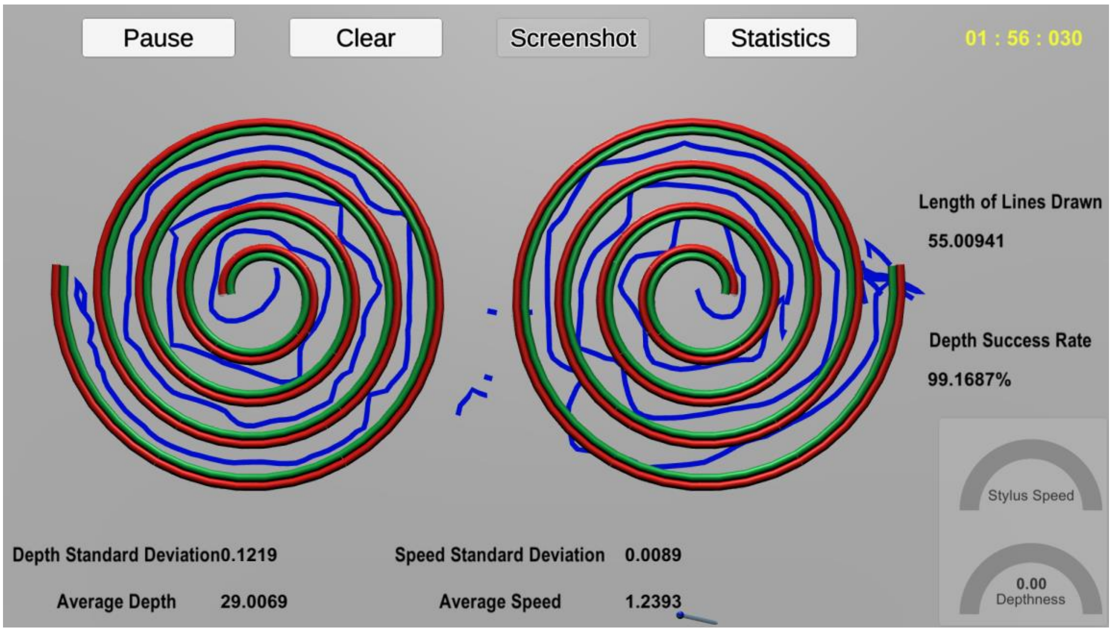

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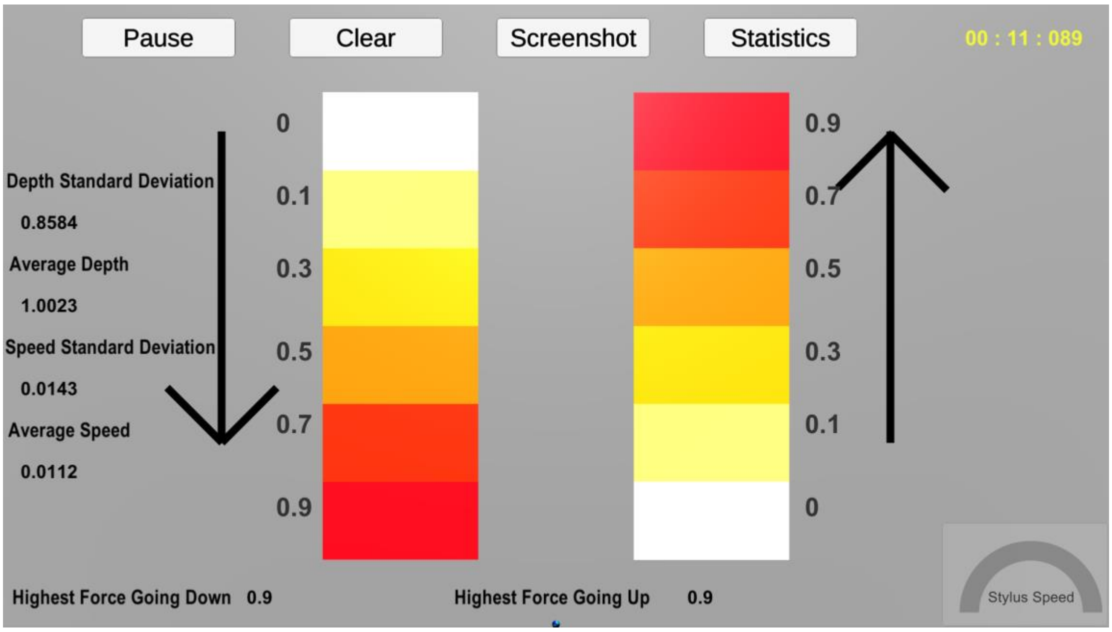

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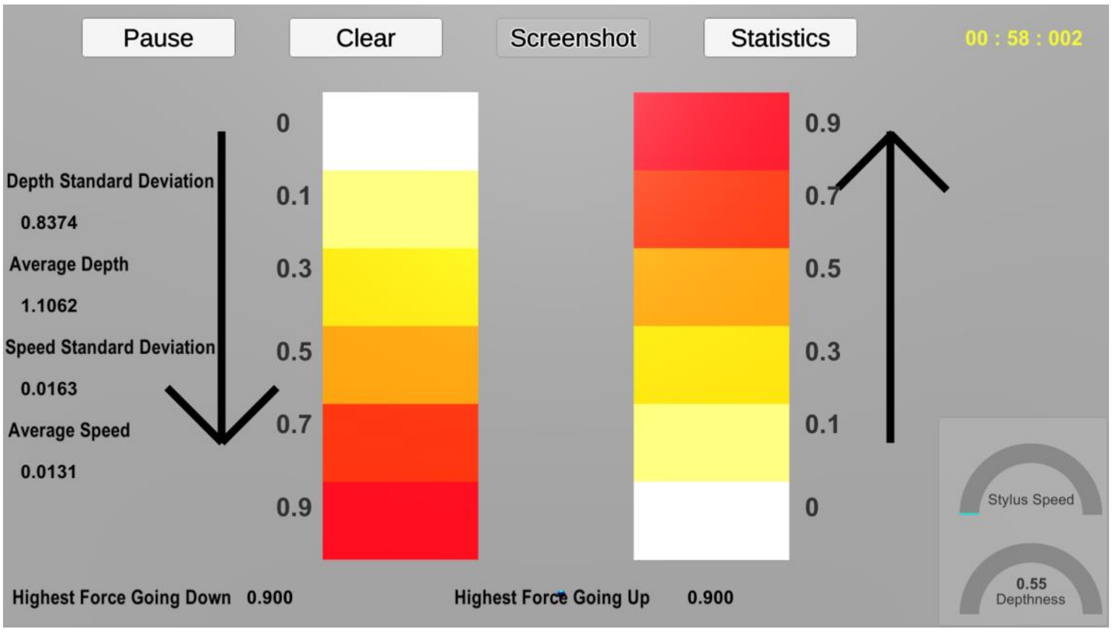
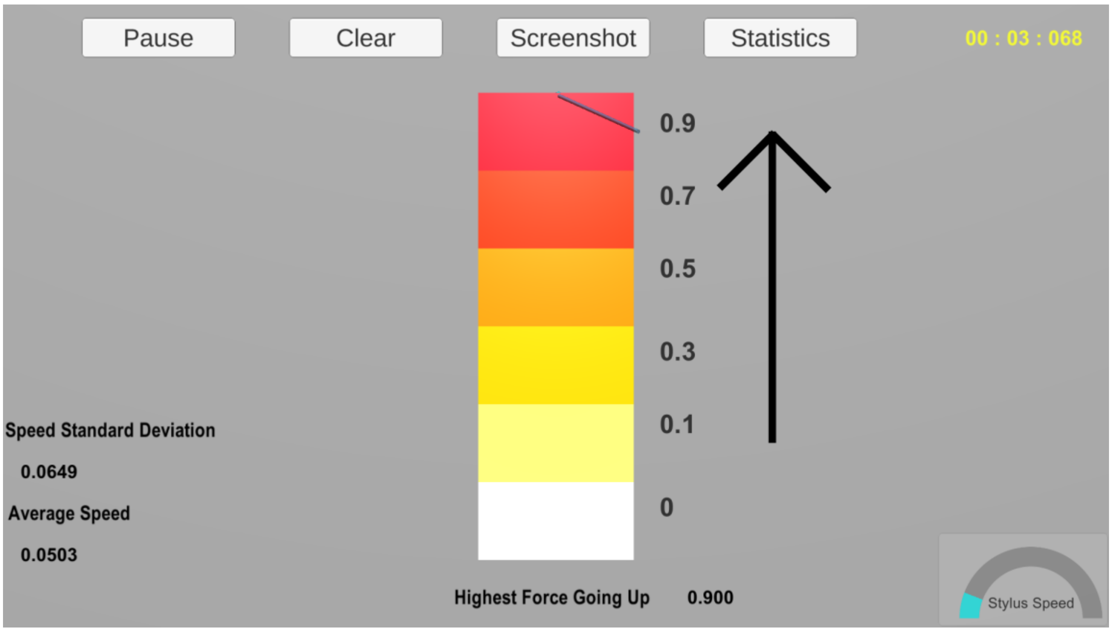
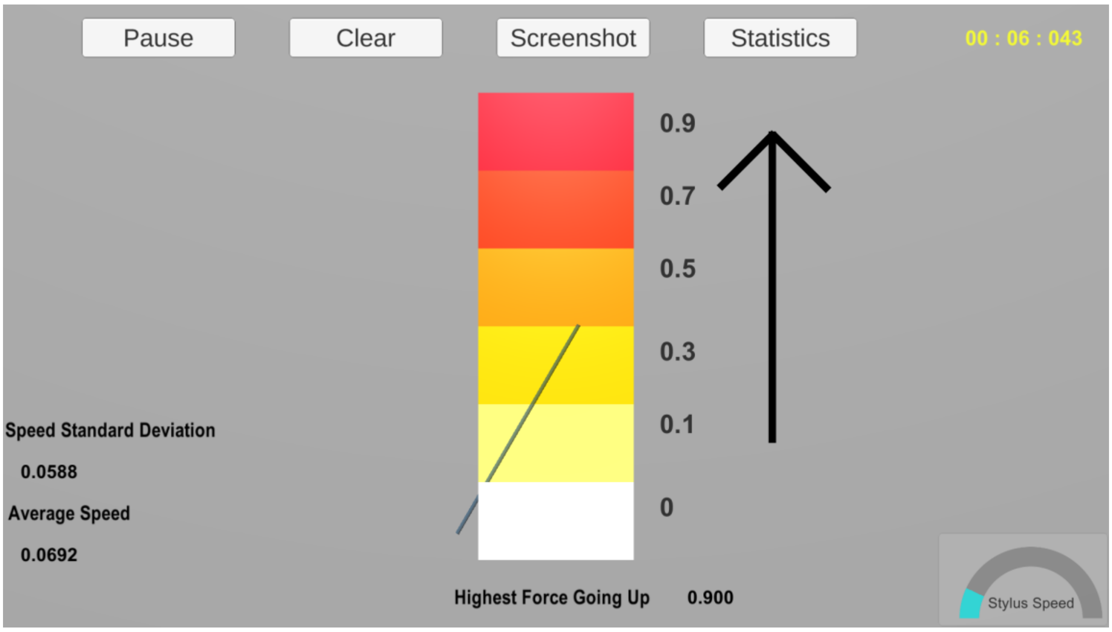


A.6 Exercise 3 Second Try Screenshot



A.7 Exercise 4 Patient 1 Wrist Extension First Try



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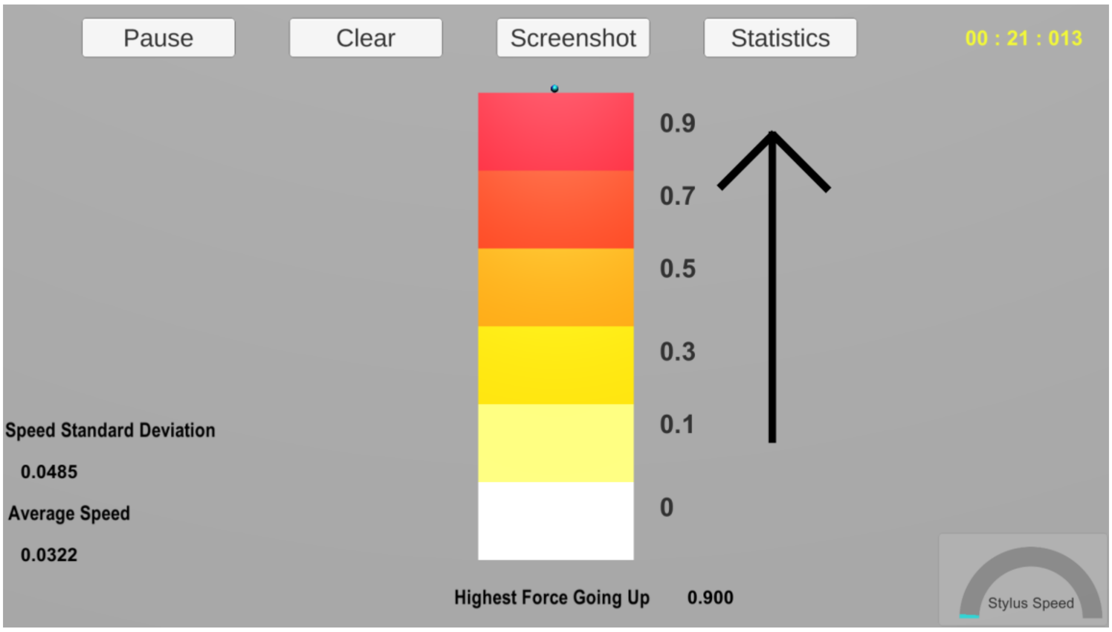
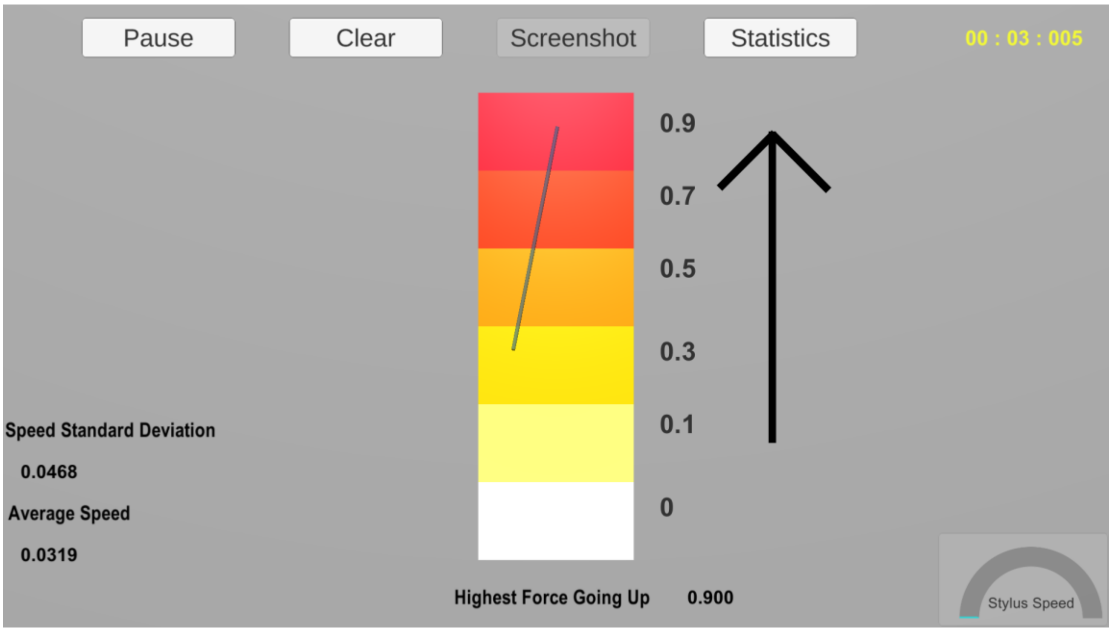
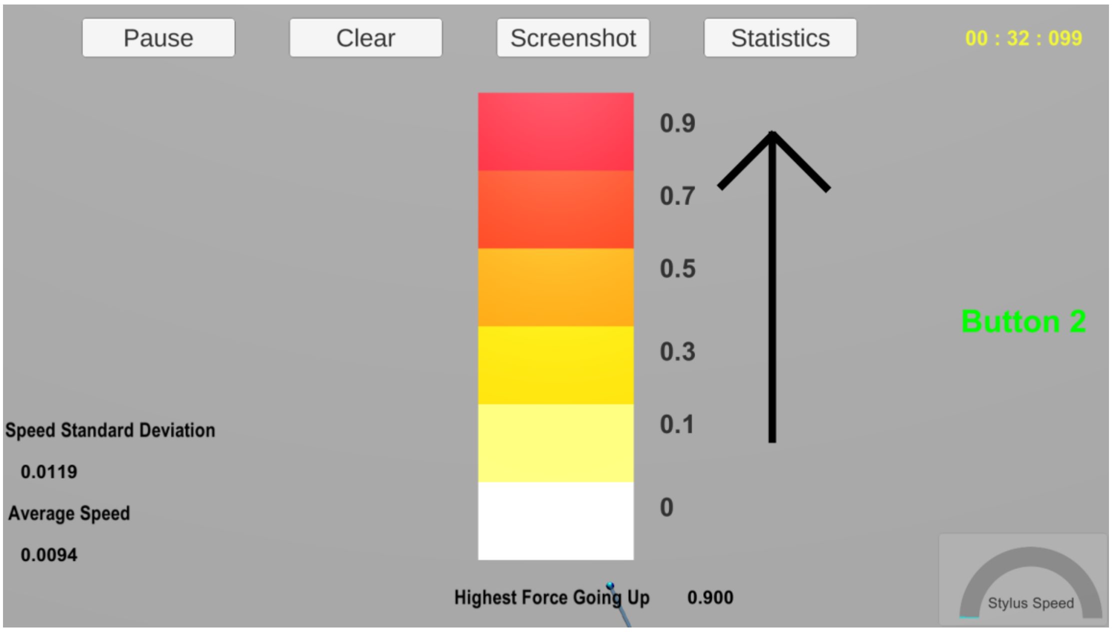


A.9 Exercise 4 Patient 1 Wrist Flexion First Try



A.10 Exercise 4 Patient 1 Wrist Flexion Second Try



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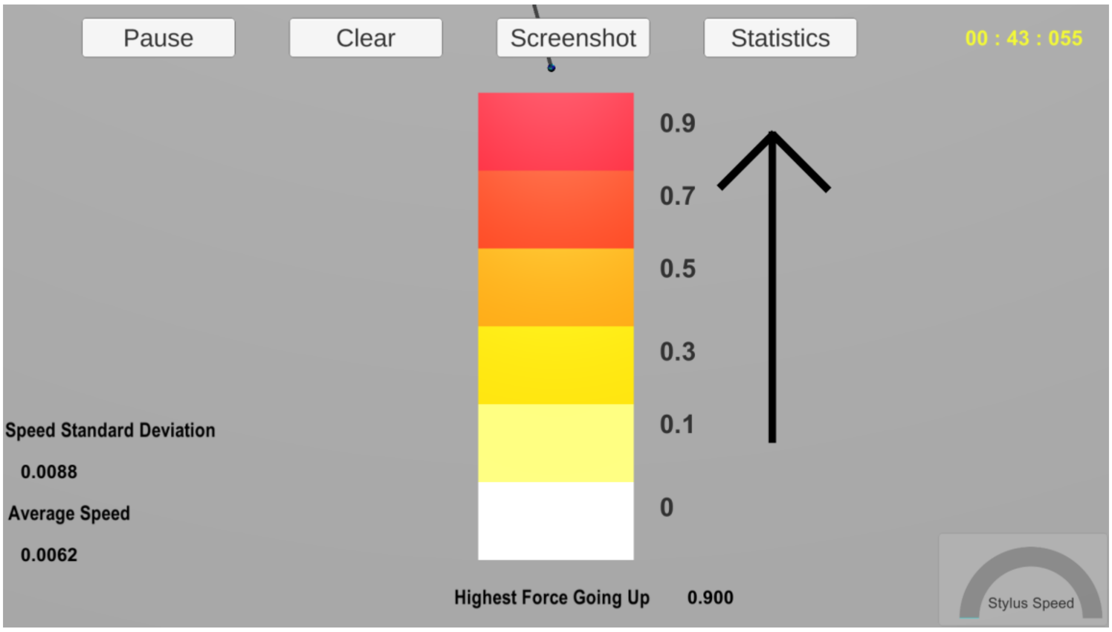

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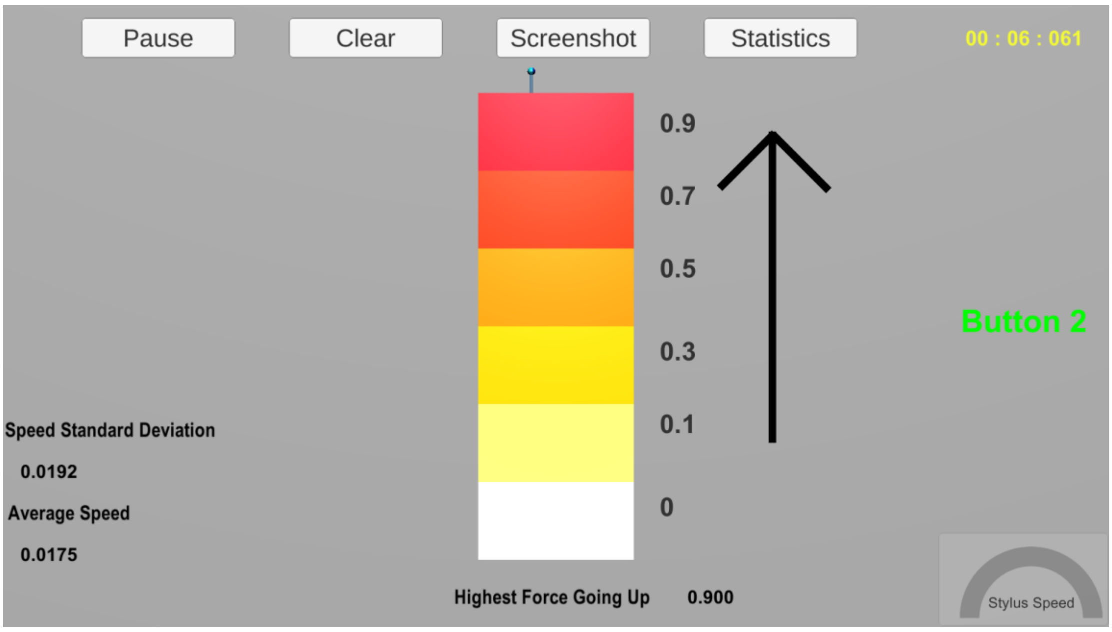

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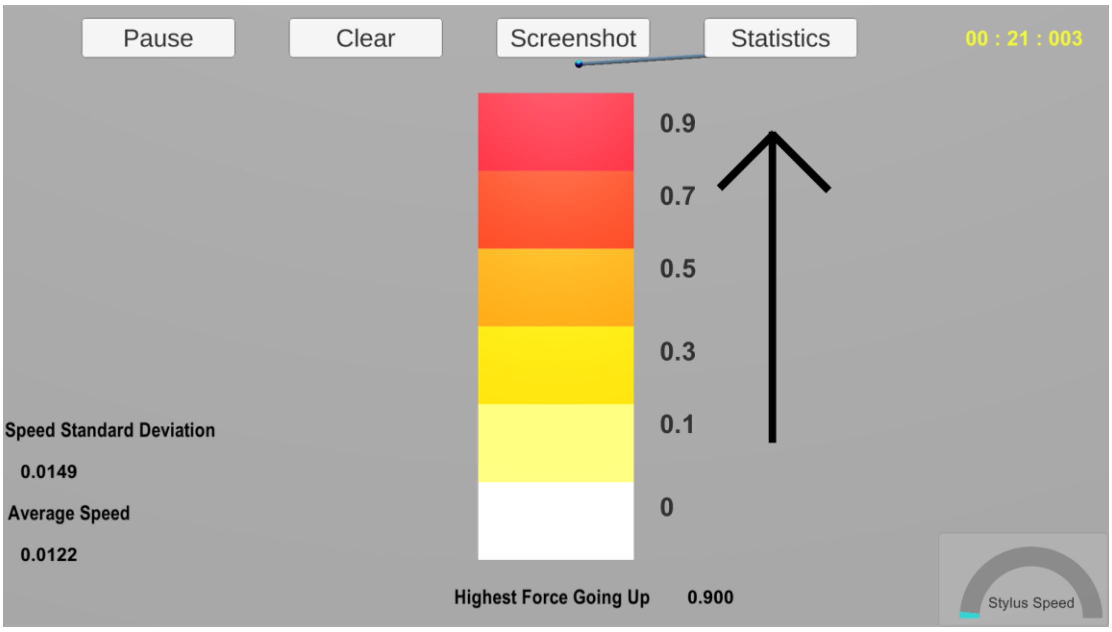
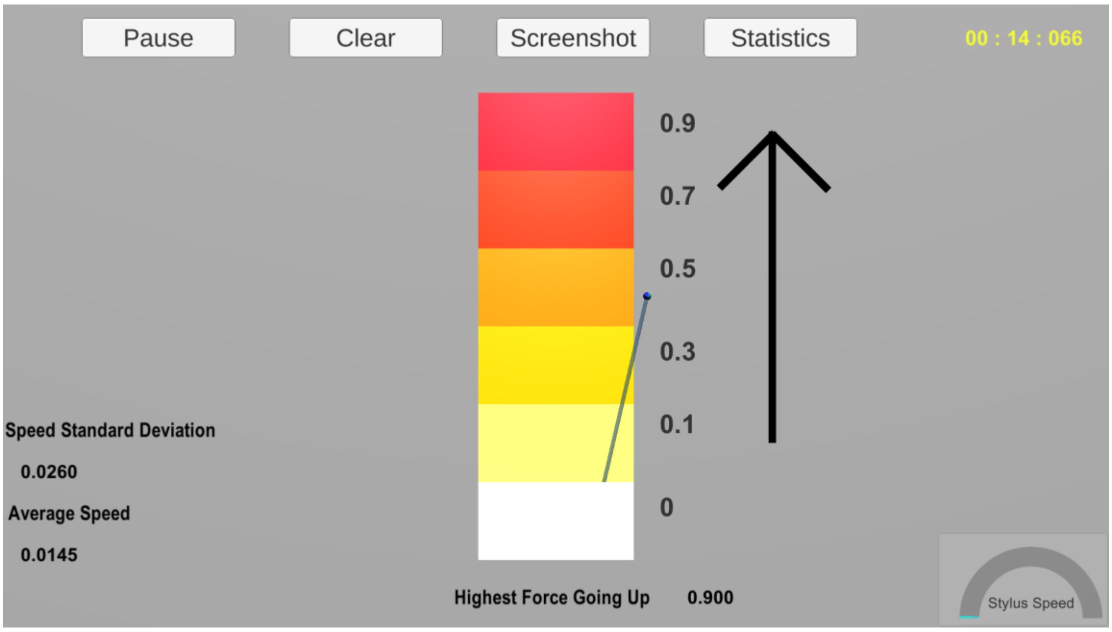
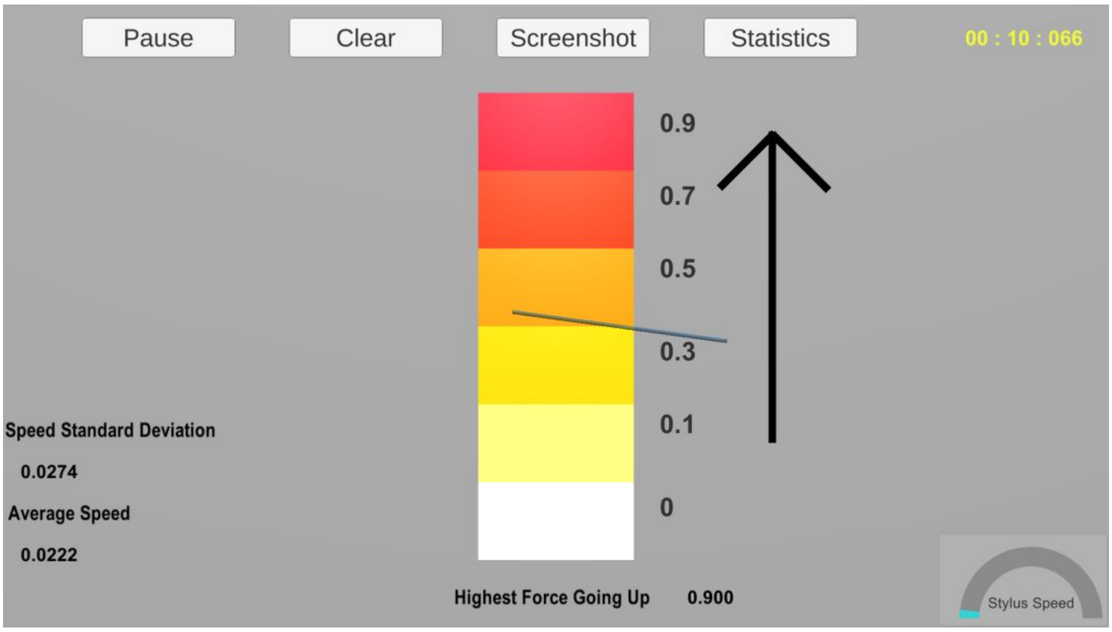


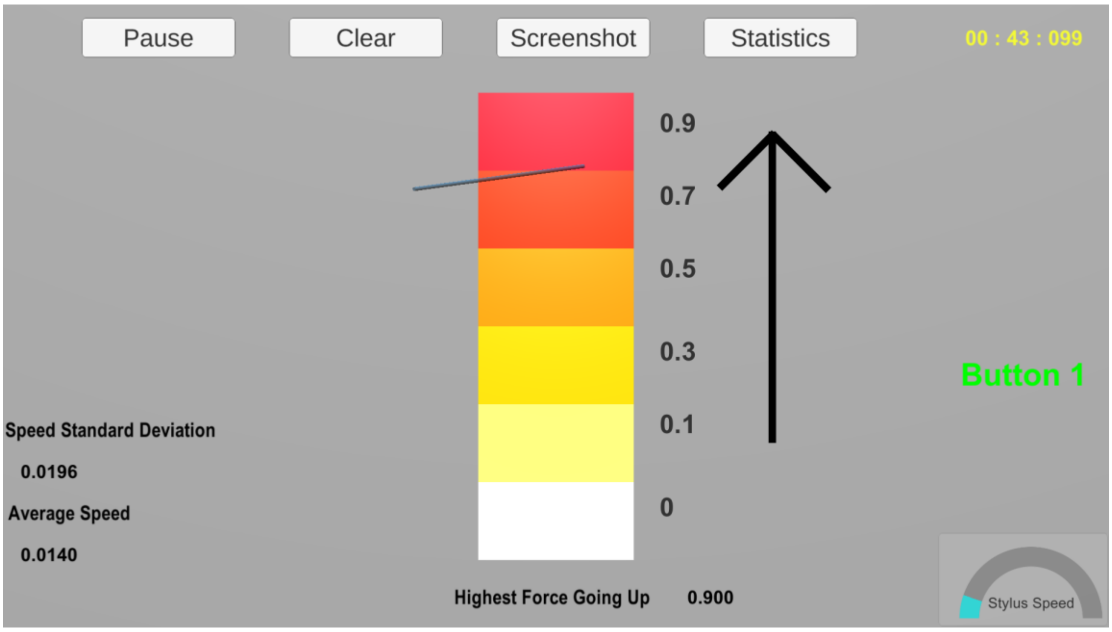
A.14 Exercise 4 Patient 2 Wrist Flexion Second Try



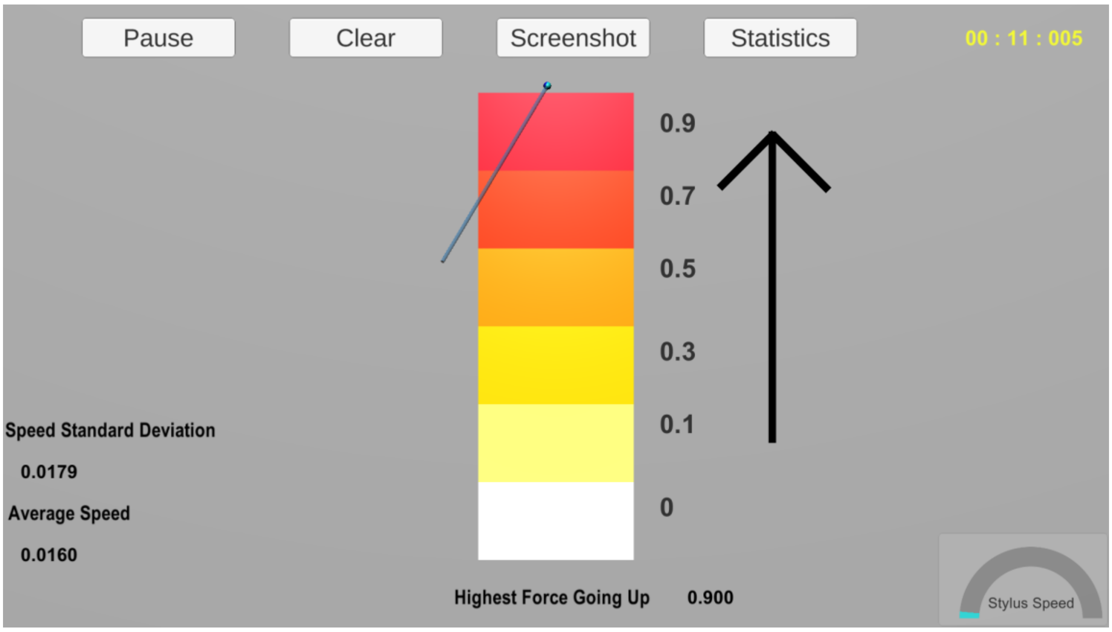
A.15 Exercise 4 Patient 3 Wrist Extension First Try



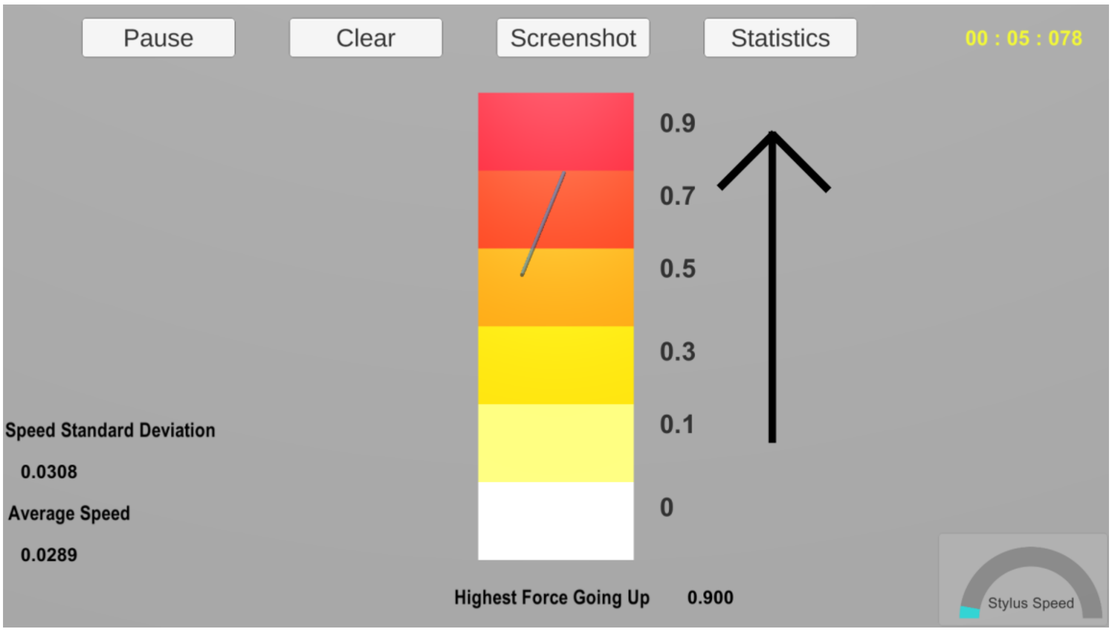
A.16 Exercise 4 Patient 3 Wrist Extension Second Try



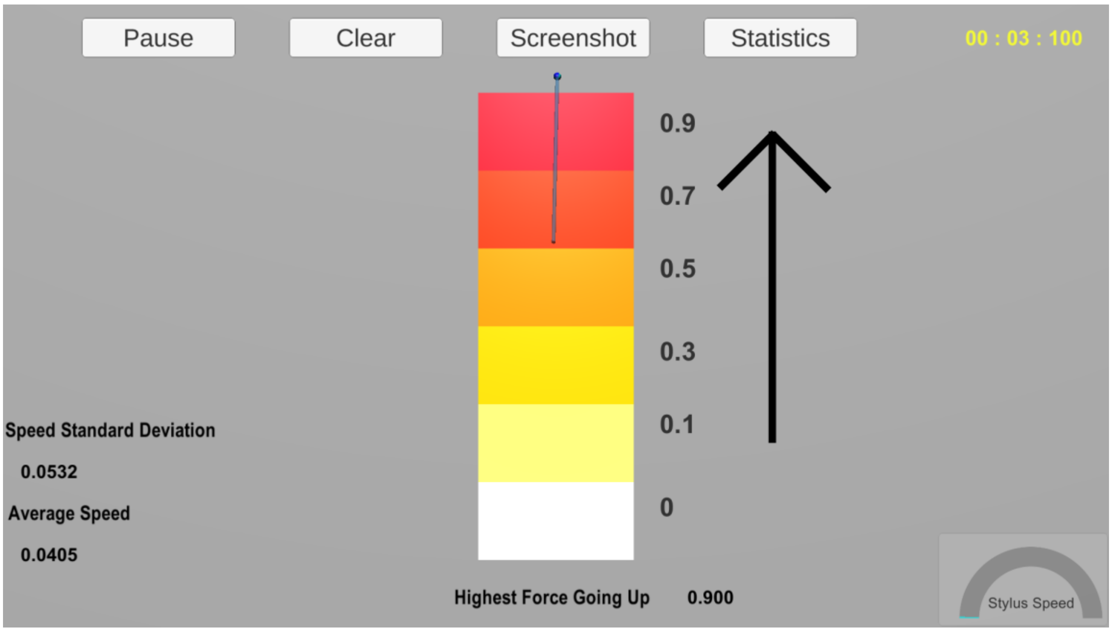
A.17 Exercise 4 Patient 3 Wrist Flexion First Try



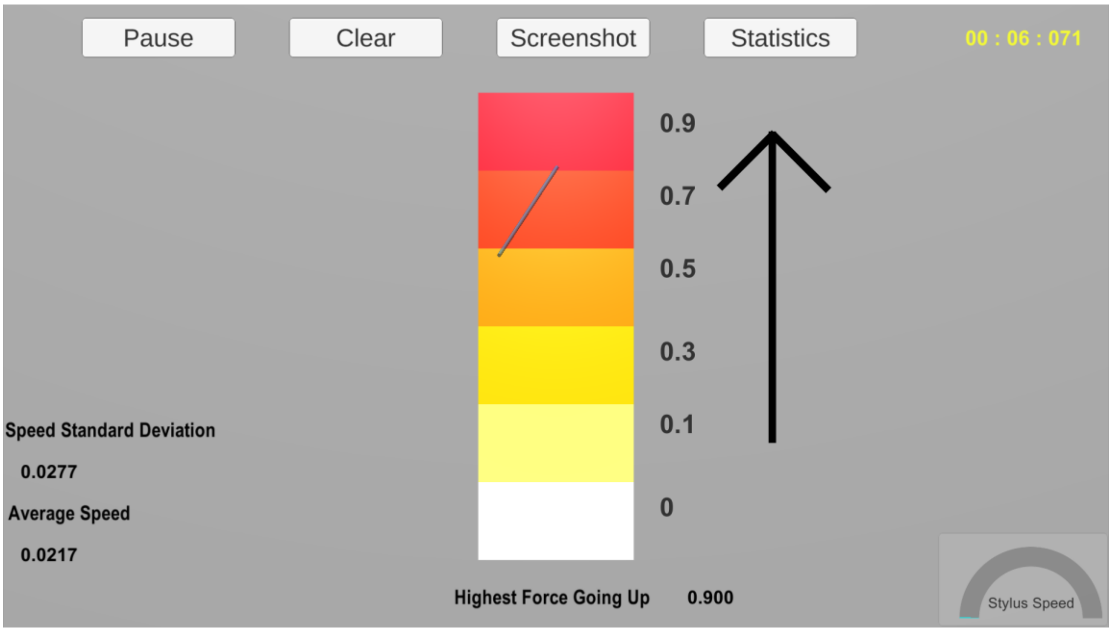
A.18 Exercise 4 Patient 3 Wrist Flexion Second Try



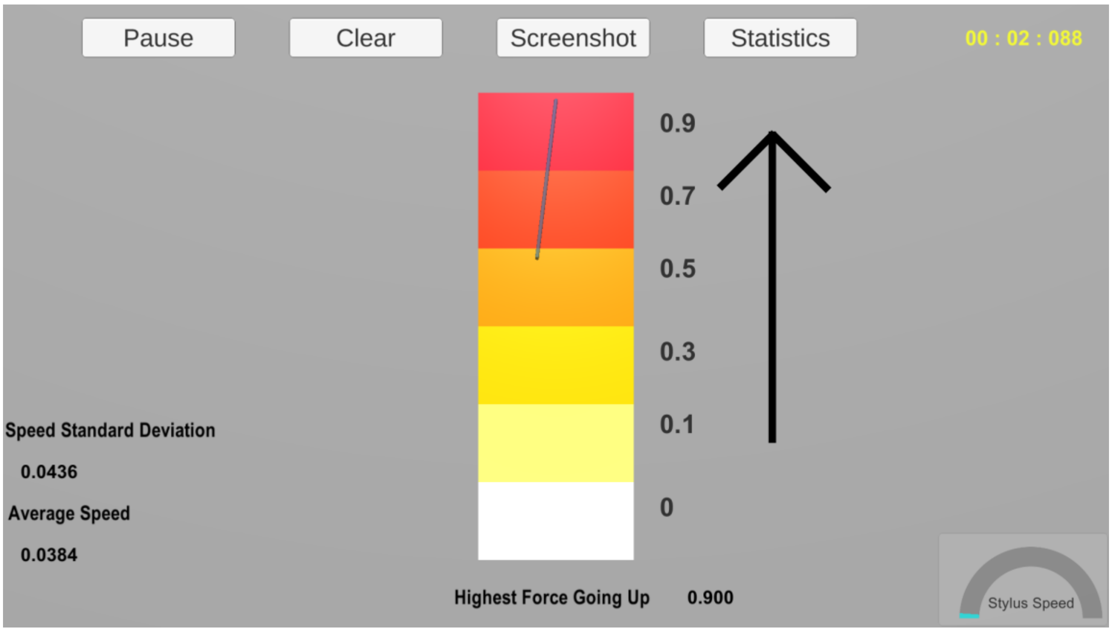
A.19 Exercise 4 Patient 4 Wrist Extension First Try



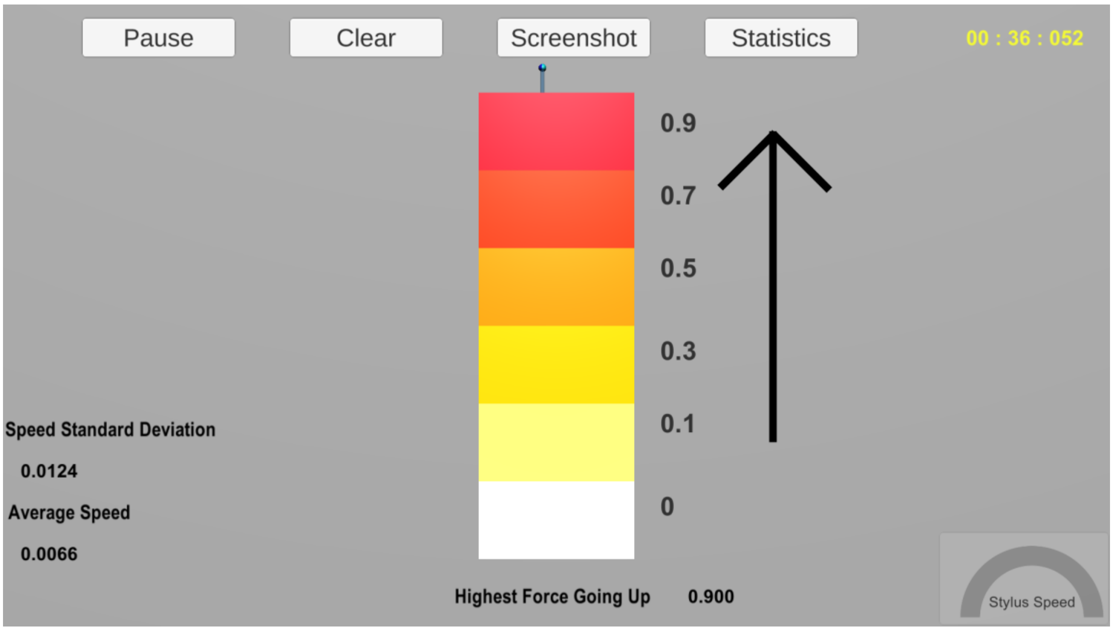
A.20 Exercise 4 Patient 4 Wrist Extension Second Try



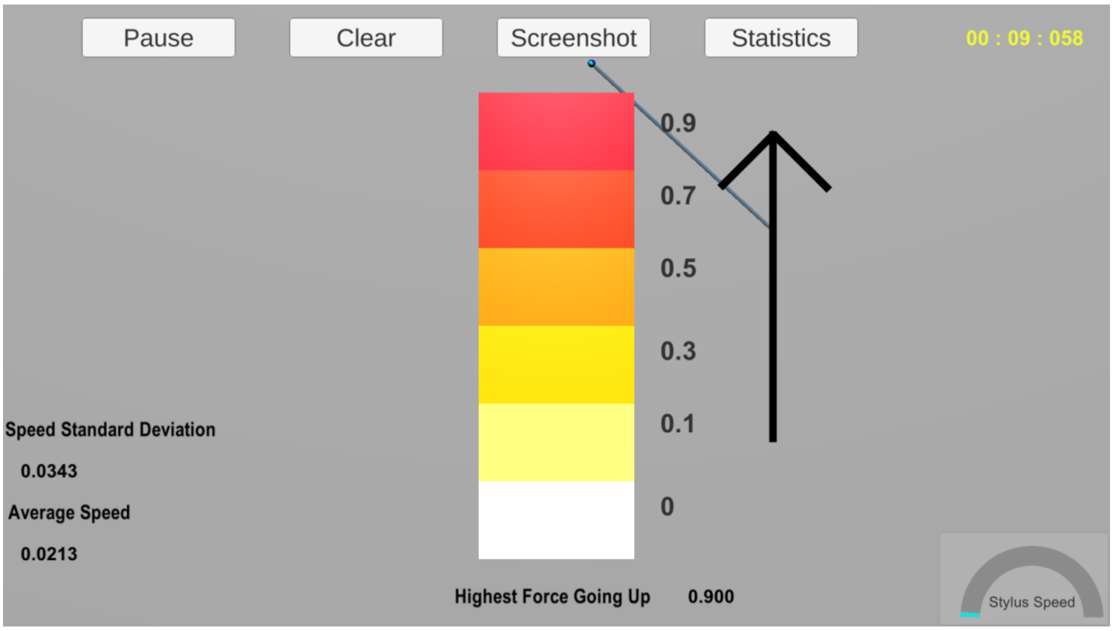
A.21 Exercise 4 Patient 4 Wrist Flexion First Try



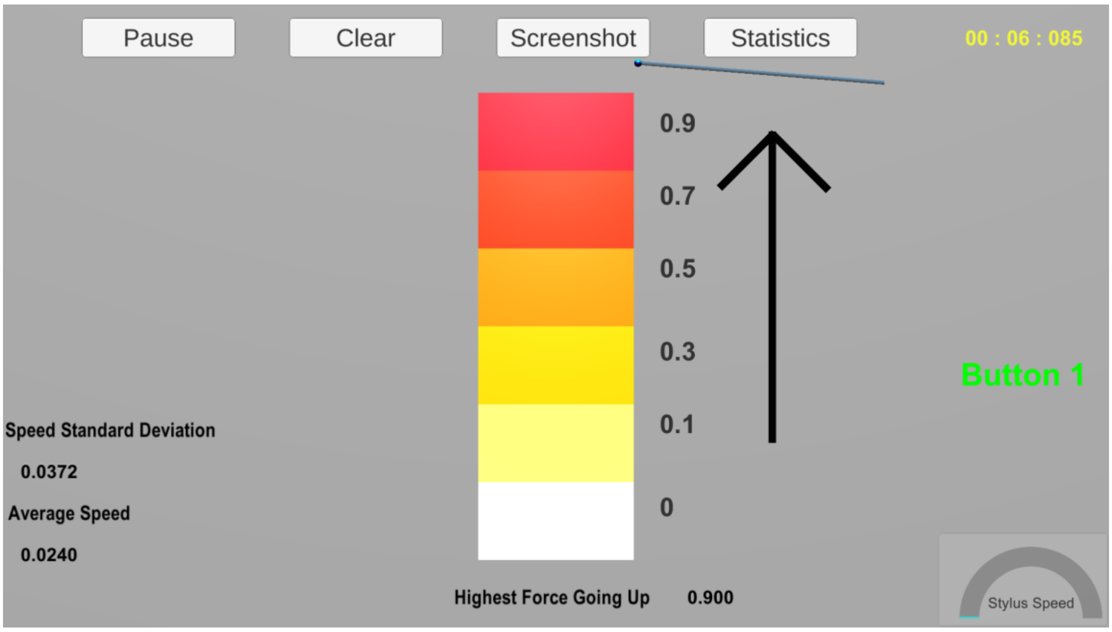
A.22 Exercise 4 Patient 4 Wrist Flexion Second Try



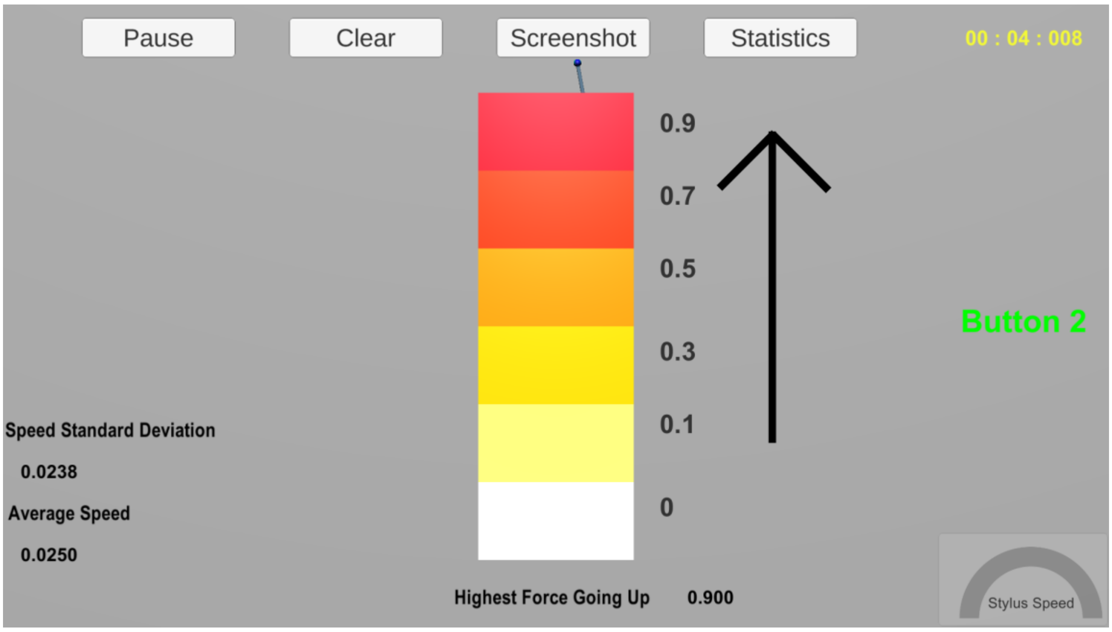
A.23 Exercise 4 Patient 5 Wrist Extension First Try



A.24 Exercise 4 Patient 5 Wrist Extension Second Try



A.25 Exercise 4 Patient 5 Wrist Flexion First Try



A.26 Exercise 4 Patient 5 Wrist Flexion Second Try

Poster

HAPTIC TOUCH TO IMPROVE MOTOR SKILLS AND SENSE OF TOUCH OF STROKE PATIENTS

Chow Tec Soon

Supervisor: Dr. Manoranjitham

Introduction

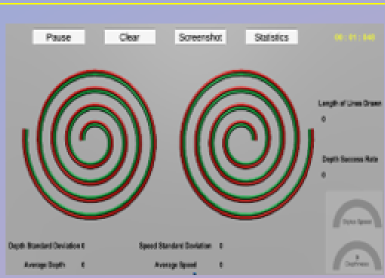
A stroke is a medical condition in which the brain cells die due to poor blood flow. It can be fatal but for those who survived, disabilities will most likely affects them afterwards. Some of the disabilities are muscle weakness, numbness, difficulties carrying out daily activities and more. Stroke survivors go through stroke rehabilitation to combat the disabilities. Stroke rehabilitation helps stroke survivors to regain the skills that they have lost.

Haptic Technology

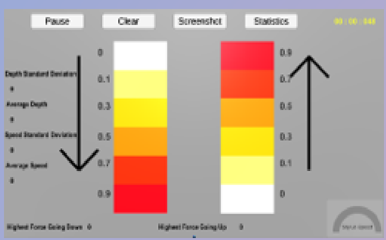
Haptic technology allows users to feel virtual objects. Some devices apply force feedback on user's hand for users feel virtual objects.

System Design

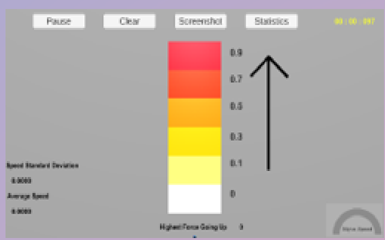
Exercise 1



Exercise 2



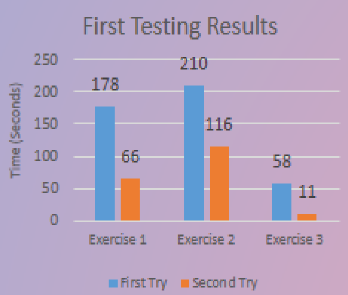
Exercise 3

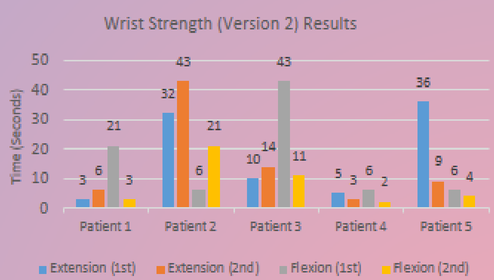


Exercise 4

unity

Testing Results





Conclusion

A technological based application that incorporates motor sensory elements is designed to help improve motor skills and sense of touch of stroke patients. The motor sensory elements in the proposed solution is used to guide stroke patients in doing exercises and improve their wrist strength.

Turnitin Report

Haptic Touch to Improve Motor Skills and Sense of Touch of Stroke Patients

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