Dynawheel Stroke Rehabilitation with Android Games

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Abstract

The Dynawheel is a novel medical device designed to improve post-stroke therapy. Current rehabilitation techniques based on traditional tools such as stress balls and elastic bands produce no quality metrics or effective method of tracking the patient’s progress beyond the therapist’s subjective evaluation. This issue is resolved when smartphone applications are integrated with the Dynawheel. Two Android applications were designed and built to maximize the Dynawheel’s capabilities, to create an enjoyable, effective rehabilitation experience for patients, and to produce quality metrics that can be used by therapists and researchers to improve stroke rehabilitation.

The games were written in the Lua programming language and debugged and tested using the Gideros game engine. Once the games were built, they were tested in clinical trials at the Johnson Rehabilitation Institute. The expert therapists were also able to provide much valuable feedback. The results of the trials were used to determine functionality and usability of the games. It was concluded that both games are usable, integrate well with the Dynawheel, and have the potential to dramatically improve post-stroke treatment.

1. Introduction

Recent developments in handheld smartphone technology have had significant impacts on virtually every field. However, the medical rehabilitation industry has been relatively unaffected. Approximately 795,000 people suffer from a stroke; 140,000 people die, and the majority of stroke patients are unable to continue daily activities. A widespread audience exists for new smartphone technology to aid in stroke rehabilitation. Recently, a new device, the Dynawheel, was developed for this purpose.¹ This innovative technology has several advantages over others commonly used for stroke rehabilitation: its simple but effective design makes it significantly more affordable and versatile than other high-tech stroke rehabilitation devices.

In order to effectively demonstrate the usability of the Dynawheel, a library of applications is necessary. The Dynawheel will enhance the efficacy of the applications in stroke rehabilitation. Using the Gideros Studio development platform and phone sensors, including gyroscopes and accelerometers, two games were designed as
an engaging method of stroke recovery. If the Dynawheel can effectively integrate well with the two applications, it can be concluded that the Dynawheel is a cheap method of bilateral upper-limb stroke rehabilitation. Long term outcomes of the Dynawheel include a decrease in the costs of recovery in clinics, quality information on patient progress, and impetus for future research to identify even swifter methods of rehabilitation.

Thus, in order to advance traditional methods of stroke rehabilitation through the development of the Dynawheel by adding to the library of existing games, two applications were designed to test the usability of the device.

2. Background

2.1 Theory of Stroke Rehabilitation and Neuroplasticity

Most stroke rehabilitation is based on the theory of neuroplasticity, which proposes that if stimulated, the brain can compensate for damage by growing new connections between intact neurons. Stroke rehabilitation therapists use this idea to help patients recover cognition, vision, and physical movement. Therapists induce neuroplasticity through repetitive exercises designed to engage the parts of the brain that control these functions.²

To bypass the damaged nerve cells, the brain rewires networks by allocating tasks to neurons that are used less frequently. This is accomplished through neurogenesis and axonal sprouting. Neurogenesis is the creation of new brain cells in the subventricular zone, where self-renewing neurons are abundant. The process involves the alteration of the rostral migratory stream (RMS), a flow of immature neurons from the subventricular zone to the olfactory bulb.³ It has long been known that the RMS controls an animal’s behavior based on external smells, but it has recently also been identified as a way to relocate immature neurons to replace damaged ones.

Axonal sprouting involves the strengthening and elongation of existing neurons rather than the synthesis of new ones. It is triggered by proteins that are released when neurons are damaged. The window for axonal sprouting is the first three to four weeks, following the injury.⁴ During this period, physical rehabilitation and cognitive stimulation, along with continuous monitoring of the patient’s condition are crucial. Since the damaged neurons are not replaced, but are instead simply “bypassed” patients rarely recover their pre-stroke conditions.

The most prevalent example of neuroplasticity is the brain’s response to the treatment of amblyopia. Amblyopia is a major cause of preventable blindness where the inability to view out of both eyes simultaneously deteriorates the capacity of one eye. Even though the eye is healthy and biologically functional, the brain is unable to process visual stimulation via the optic nerve. A traditional remedy for Amblyopia involves wearing an eye-patch over the dominant eye, effectively conditioning the amblyopic eye -- evidence that external stimulation is a catalyst for effective brain rewiring.⁵
2.2 Visual, Cognitive, and Physical Effects of Stroke

Stroke victims can experience a variety of vision problems called ocular ability impairments (OAI), as a result of damage to the brain stem. The type and severity of OAI vary depending on the location of the brain stem that is damaged. Some examples include diplopia, which can cause the patient to see double vision, visual neglect, which means the patient’s field of vision has a blind spot, and agnosia, which causes problems with depth perception, color detection, dizziness, hallucinations and object recognition.

Two common cognitive effects of stroke are vascular dementia and aphasia. Vascular dementia is a broad term characterized by a loss of cognitive functions due to restricted blood flow to a certain part of the brain. Vascular dementia can lead to memory loss, confusion, decreased attention span, and reduced problem solving abilities. Aphasia is a result of damage to the frontal and parietal lobes in the right hemisphere of the brain. Aphasia impairs a person’s ability to communicate through both written and verbal language.

Most patients also experience some form of physical impairment as a consequence of stroke. Physical impairments tend to be dominant on one half of the patient’s body since each half of the body is controlled by a different hemisphere. Therefore, the impairment is more evident on the side controlled by the hemisphere where the injury has occurred. Eighty-eight percent of stroke victims suffer from hemiparesis or hemiplegia. Hemiparesis is the weakening of one half of the body while hemiplegia is the paralysis of half of the body. Stroke victims also undergo a type of paralysis known as spasticity, causing muscles to stiffen.

The degree to which patients exhibit visual, cognitive, and physical effects of stroke varies greatly, underscoring the need for flexible, customizable therapy techniques. The overall purpose of therapy is to help the patient resume as many activities of daily living (ADLs) as possible. Therapists commonly use ADLs as an indicator of patient progress. Some examples of ADLs include shopping, driving, eating, and bathing, all of which require a high level of visual, cognitive, and physical functioning.

2.3 Bilateral Rehabilitation

In recent years, there has been a trend towards bilateral rehabilitation. The idea behind bilateral therapy is that the stronger half expedites the recovery process for the weaker half as the dominant limb assists the secondary limb in performing bimanual tasks. Bilateral rehabilitation has been shown to be an effective method of addressing the effects of stroke.

Bilateral movements can be categorized into three classes. The most rudimentary class consists of symmetrical movements in which the right and left limb move in a congruent fashion. This class involves actions ranging from lifting and carrying, to pushing and catching. The second class of bilateral movements involves the two arms performing the same
task, but in an anti-parallel motion. Such movements are detected in running, climbing ladders, and boxing. The last of the bilateral movements are bilateral complementary. The two arms cooperate in performing the same task but rely on different motor movements. These movements are the most complex and involve a dominant hand manipulating and performing the task, while the secondary hand stabilizes and executes a more supportive role. Although both limbs are controlled independently, research shows that a neural link is used for bilateral activity. This connection is severed after a stroke but can be reformed through bilateral rehabilitation.

The most common technique of bilateral rehabilitation is repetitive isolated muscle training. The main muscles of focus are located at the wrists. Exercises include wrist flexion, extension, pronation, supination, and radial and ulnar deviation (Figure 1).

![Figure 1: Wrist Movements](image)

Despite all the movements being solely concentrated at the wrist, muscles are strengthened in proximal as well as distant regions, as evidenced by the Bi-Manu-Track study. The Bi-Manu-Track is a robot that allows hemiparetic patients to practice wrist flexion, extension as well as pronation and supination. This device focuses on bilateral therapy to strengthen connections in the corpus callosum, the midsegment of the brain that coordinates signals between the left hemisphere to the right hemisphere. Strengthening the fibers will promote ADLs and improve the paretic side. The device also concentrates on distal upper-limb movements rather than proximal ones. Proximal upper-limb body parts contend for cortical memory and brain plasticity and impede the progress of distal upper-limbs, such as hands and fingers.

2.4 The Dynawheel

Development of the Dynawheel, a passive device used for stroke rehabilitation, began development in January of 2011. Depending on the application, it can be positioned perpendicular or parallel to a surface. It features two triggers with interchangeable springs. There are three available springs - green, yellow, and red - with red having the lowest spring constant value, and green having the highest. Each spring also contains a small magnet; by compressing the spring, the distance between the magnetometer in the phone and the magnets themselves are reduced, strengthening the magnetic field detected by the phone. The amount the springs are squeezed is acquired using a call to a Java function that reads raw sensor input measured by the Android smartphone’s magnetometer. The conversion to percent squeezed from the function output is
controlled by a driver previously created by other researchers working on the Dynawheel. The phone’s magnetometer is not as accurate as incorporating the springs into an electrical circuit because of the variability in magnetic fields depending on the position of the phone; however, using the magnetometer is much less expensive. The entirely non-electric design ensures affordability for rehabilitation facilities.

The Dynawheel also features different mounts to keep it upright on a table. As of now, current mounts include a single ball-bearing mount, allowing the Dynawheel to pivot on the table and a four-ball-bearing mount system allowing for lateral movement. Mounts can be removed for games that require the Dynawheel to be suspended in air; however, the mount is often necessary for the most severely affected stroke patients because it provides extra stability.

The Dynawheel is a flexible tool that is designed to improve all stages of stroke rehabilitation. The flexible and portable design makes it useful to many types of rehabilitation services including inpatient, nursing facilities, outpatient, and home-based rehabilitation.

The Dynawheel has several benefits over other commonly used devices. Its simple design makes the Dynawheel very versatile and affordable. It features interchangeable bases, two triggers, and most importantly, a smartphone mount. These features allow the Dynawheel to be used as a gaming interface suitable for rehabilitation. This has benefits for the patient, the therapist and the rehab facility. The gaming approach makes rehabilitation sessions less tedious for the patient. The applications provide much useful information about patient metrics for the therapist. As the patient is gaming, the phone can electronically record important information such as grip strength, grip release, flexion, extension, and endurance time as well as keep track of and analyze performance from previous sessions. These digital quality metrics can be cited by the rehabilitation facility as evidence based outcomes. The therapist can use the produced data to improve their techniques and to research the efficacy of their methods.

Currently, few games exist that are compatible with the Dynawheel and are appropriate and beneficial for stroke rehabilitation. To contribute to the library of games for the Dynawheel, two Android games were created to maximize and test the Dynawheel’s capability as well as help patients gradually resume ADLs.

3. Experimental Design

3.1. Obtaining Hardware

The applications were developed and tested on the LG Nexus 4 and Galaxy S4 but can run on any Android or iOS device. The games were tested using the current Dynawheel prototype. During user testing, the Android devices were mounted on the front of the Dynawheel horizontally with Velcro straps.
3.2 Obtaining Software

Gideros, an intuitive Lua-based cross-platform development kit for Android and iOS, was used to develop the games. The IDE also has debugging capabilities on a real phone; it is possible to export the project then completely package it into an Android Package (APK) and install it onto the phone, or use Gideros Studio’s wifi-dependent debugger.

To produce Android deployment instances of the games, the games were first exported from Gideros Studio to a Java project. For each game, an unsigned APK was created through the Eclipse development environment then uploaded to the phone. From the phone, the application was installed. In addition, the application can also be deployed to an iPhone if an Android is not available. The self-explanatory nature of Gideros and its diverse debugging features make it learnable within a week.

Despite its simplicity, Gideros has several drawbacks; the exporting process and debugger are not reliable in areas with weak or no wireless network signal and the error messages in the stack trace are vague and unhelpful. In the future, Java might be a more efficient option for developing Android apps, as Gideros’s cross-platform capabilities are not important if therapists prefer Android smartphones and tablets.

3.3 General Game Design for Stroke Rehabilitation

The games are stimulating and significantly more engaging than the simple, repetitive tasks that therapists usually administer. However, the game layout must be very minimal because some patients may be distracted by complex graphics and background noise. Patient frustration can hinder progress, so it is vital to have gameplay options that the therapist can adjust as the patient progresses. Research has shown that it is important to gradually increase the complexity of the game to develop the cognitive function of the patient.\(^3\)

3.3.1 Requirements

Since research was limited to a timespan of a month, the task was to design applications that test the usability of the Dynawheel rather than the efficacy. Testing effectiveness would require monitoring several patients over the course of several months to mark improvement, while comparing it to other traditional and contemporary stroke rehabilitation methods. To comprehensively test usability, it was necessary to design games that integrate Dynawheel's unique features -- unique phone case, spring-magnet complex, easy grips, mounts -- while also exercising the major wrist movements and grip strength.

Antithetical approaches were used to design the two games. Since the absolute objective is to allow the patient to resume ADL's, the games were designed with that
sole purpose. One approach was to consider an actual ADL and loosely mimic that function with a game. The Veggie Catcher was designed with the premise that stroke patients lack the motor coordination to pick up objects for an extended amount of time; thus, the game involves simulating picking up vegetables while integrating the Dynawheel spring-magnet complex and its real life application is tangible. The other approach was to consider motor movements typically used in an ADL and design a game that incorporates such motor movements. The Maze Race, a two-dimensional maze navigation game, includes the major wrist movements and trains the steering motion associated with driving a vehicle. It primarily uses the Dynawheel as an exterior assister that enables the stroke patient to achieve a more effective exercise while gaming; however, the association with an ADL is subtle.

Since usability was emphasized rather than capability, the two games were designed using two different phone sensors. The Maze Race uses the phone gyroscope, which detects angular deviation, and changes the visuals in game accordingly. Thus, this game is played in a vertical position. However, to test the usability of the applications and Dynawheel in a horizontal position, the Veggie Catcher game was designed using the phone's accelerometer. The accelerometer’s ability to detect the gravitational force requires a horizontal position for gameplay, as playing in a vertical position would result in all in-game objects falling straight downward under the effect of gravity; tilting of the phone in any direction is detected by the accelerometer, and the graphics in game are updated based on the accelerometer readings after applying a low-pass filter. The reason for implementing both an accelerometer and the gyroscope was to ensure different playable positions for the Dynawheel. Holding the wheel horizontally, as in holding a plate, and holding it vertically, as in holding a steering wheel, are distinctly different experiences.

Lastly, because patients can experience different severities of stroke and may be at different stages of rehabilitation, the games must have adjustable settings and levels. Since victims also suffer from aphasia and sight ailments, the graphics of the game must contain little background noise, have simplified symmetrical and recognizable shapes, avoid extravagant and excessive coloring, and be as minimalistic as possible. These parameters were prerequisites in the designing process.

3.3.2 Designing Maze Race

The Maze Race game, shown below, involving a character navigating through a maze, saw success at alpha testing with a local rehabilitation clinic using two different modes of gameplay with the Dynawheel: unimanual and bimanual.

The Maze Race game (Figure 2) takes advantage of the Android’s gyroscope to guide an avatar through a series of increasingly difficult mazes. The rate of rotation of the Dynawheel is recorded by the Android gyroscope and used to control the speed of the character on the screen.
Angle of rotation is calculated by a simple integration formula, programmaticaly approximated with a Riemann sum. Let $M$ be maximum speed, $\omega_z(t)$ be the rate of rotation around z axis at a specific time (rad/s), and $\omega_y(t)$ be the rate of rotation about y axis at a specific time (rad/s). $\theta_z(t)$ is the angle of z rotation (radians) and $\theta_y(t)$ is the angle of y rotation (radians), calculated by the simple integral as follows:

**Equation 1:** $\theta(t) = \int_0^t \omega(t) \, dt$

**Equation 2:** $v_y(t) = \frac{\theta_y(t) \times M \times 2}{\pi}$

**Equation 3:** $v_x(t) = -\frac{\theta_x(t) \times M \times 2}{\pi}$

The velocities of the character are then calculated by Equations 1 and 2.

Since stroke patients suffer from visual defects, such as OAIs, and a shortened attention span, graphics are minimal and colors were contrasted to encourage the patient to focus on the game. While the patient is playing the game, deviation range of motion, time, score, and endurance are all recorded. The game ends when the patient successfully completes all five mazes; the time required to complete the game determines the final score displayed and an indicator of progress. Since the patient can control the speed of the avatar with the degree of ulnar and radial deviation -- radial deviation moves the avatar down the screen and ulnar deviation moves the avatar up the screen -- a patient with improved motor control and a wider range of motion can complete the game in a shorter amount of time by adeptly controlling both speed and accuracy. Thus, a more improved patient will typically receive a, lower time for completion.

Different modes of gameplay with the Maze Race game include using the Dynawheel free in the air, straight up on the table, or mounted straight up on a stand. The different modes allow the therapist many options for therapy gaming based on how much stability and freedom the patient needs for proper movement. It is also one manifestation of the different degrees of difficulty customizable for the game.

Holding the Dynawheel without its stand requires significantly more upper body strength and the use of several balancing muscles. However, it is necessary in some cases as it permits a greater range of motion. The wheel can be placed on a table yet still move through the full range of motion required to complete the game, albeit at a much slower pace. However, it is easier for the patient to control and requires significantly less upper body strength; thus, the Dynawheel itself is a suitable system of gauging difficulty of the game and the progress of the patient.

If the Dynawheel is attached to its stand and placed on a table, it is locked into place, allowing only very slight tilting of the
wheel, making gameplay significantly easier. This setup increases wheel stability, and does not require as much upper body strength, as if the patient accidentally loosens the grip, the Dynawheel will stay in its upright position. This setup is ideal for patients with very limited motor control and wrist range of motion.

Because strokes range in different levels of severity, a level system for each game was used depending on the strength of the stroke and the stage of recovery. While some patients are able to effectively control one hand and slightly control the other, in more severe cases motion is much more restricted. To deal with the variability in patient motion capabilities, the therapist is able to choose the difficulty level, effectively skipping the easier levels as well as track individual patient progress. In the Maze Race, the patient progresses through the game and the levels get increasingly difficult.

The Maze Race concept itself does not represent an ADL, but it does simulate the steering motion associated with driving and obstacle avoidance. Steering is an important ADL that requires coordination and control of multiple muscle groups in upper body limbs. The game targets two major wrist movements: ulnar deviation and radial deviation. These wrist movements are fundamental to countless ADLs.

3.3.3 Designing Veggie Catcher

The Veggie Catcher game, shown below, has controls similar to the Maze Race game but runs with different device software. The game uses four major wrist movements (radial and ulnar deviation as well as flexion and extension) to guide a virtual hand, as well as the grip-system in the Dynawheel to simulate the grasping of an object. The objective of the game is to transport vegetables on one end of the screen to a basket on the other end in a bounded amount of time.

![Figure 3: The Veggie Catcher](image)

The initial specifications for the game included minimal graphics and incorporation of repetitive wrist motions. To ensure patient concentration, the game included a simple blue background, kept the text and exit button in the corners, and instead emphasized the virtual hand and the vegetables through color contrast. The colors of the basket also blend into the background but are not invisible -- this directs attention towards the hand rather than the end point.

The repetitive hand movement implementation depended on phone software. Unlike the Maze Race, Veggie Catcher is based on accelerometer values rather than a gyroscope. The accelerometer measures the movement of a thin silicon comb inside of a housing that is situated on
the phone. The comb and the housing constitute a differential capacitor. As the silicon in the accelerometer bends under various external forces, current will flow. The device converts the current to measures of acceleration; this value is integrated twice to get the position of the object. Because the accelerometer relies on the inconsistent silicon vibrations, the values of acceleration will fluctuate even under rest. To compensate, a low-pass filter was applied, essentially an exponential moving average (EMA). The EMA is a type of infinite impulse response that applies a weighed filter to each measured value. Since weighting for old data decreases exponentially and only approaches zero, this type of filter is infinite. The calculations used for the accelerometer in the game requires a recursive formula:

\[ x_t = a_t \]

for \( t > 1 \):

\[ x_t = f*a_{t-1} + (1 - f)*x_{t-1} \]

The low-pass filter is not only important for smoothing the actions of the accelerometer -- it also allows for adept customization of the speed of the hand in game. The filter value, \( f \), affects the value of weighting increase. A lower filter value will discount new accelerometer measurements and weight previous observations higher. A higher filter value will cause previous measurements to decrease faster. Although a higher filter value causes more vacillations in data, it is more responsive. In game, a lower \( f \) value creates a bigger delay between phone movement and sprite movement, decreasing speed and increasing the response time needed for accuracy -- suitable for patients with more severe cognitive effects and a higher reaction time. A higher \( f \) value causes the sprite to have minor vibrations, but also decreases the lag time between phone and sprite movement, while also increasing the speed of the sprite. The patient must have a decent reaction time to efficiently navigate through this setup. Allowing for a customizable filter value gives therapists more freedom of control.

In addition to the speed of the object, the therapist is able to select different difficulties and settings with the in-game menu. The settings will be displayed each run and the therapist gets full jurisdiction and is able to customize the game in accordance with each patient’s abilities. For example, different levels may involve a consequence if the vegetable is “dropped” such as resetting the vegetable to its original position without incrementing the score count.

An optional magnetometer gameplay mode to make the game more complex can be set up under the therapist’s judgment. With this option activated, the patient must squeeze the springs on the side of the Dynawheel to simulate the grasping of an object, then release the grip to release the object. The grasping motion picks up the vegetable if the hand is hovering over it, then the release of the grip drops the apple in the basket if the hand is right over the basket. This technique trains grip strength; however, some patients cannot fully grasp the handle, making it vital for this mode to be voluntary.
Additional difficulty options in the game also involve a vegetable reset, where if the vegetable is not properly positioned, the vegetable will be reset to a random position -- this advanced form of the game encourages steady hand movements and greater precision. Each game lasts a certain amount of time that is also controlled by the therapist, and the patient attempts to direct as many vegetables into a specified location in the time allotted. Greater motor control in the patient will allow for a higher score. Because this game is not as architecturally simple as the Maze Race game, but conceptually similar, a menu with many game modes that vary the difficulty of the game is offered to the physician. Veggie Catcher is designed to improve coordination, motor and cognitive skills required for everyday activities such as transporting objects over short distances.

3.4 Clinical Trials

Clinical trials were conducted at the Johnson Rehabilitation Clinic in Edison, NJ on July 17. Two therapists reviewed both applications. The experience provided much valuable feedback to improve the usability of the applications and the Dynawheel. Then a male in his fifties who had suffered a stroke a few months earlier tested The Maze Race with the Dynawheel. Due to internet connectivity issues, the patient was only able to test The Maze Race unilaterally and bilaterally (Figure 4); however, relevant feedback for the Veggie Catcher game was also given by the therapists.

![Figure 4: Unilateral (top) and Bilateral (bottom) Controls](image)

3.5 Adding Metric-Recording Functionality

After the games were built, debugged, and tested for usability, metric recording support was added. As a patient plays the game, the application records and keeps track of six metrics; score, time, deviation range of motion, maximum ulnar deviation, maximum radial deviation, and endurance time. The therapist and patient can access this information for all sessions using progress reports that are saved for each user. The dates of each session are also recorded to create pertinent graphs that track
patient progress as well as allow for statistical analysis. These records can be adequately used to compare the Dynawheel method of stroke rehabilitation to other devices. However, the time constraints and deficiency of test subjects do not warrant for the long term patient monitoring.

4. Results & Discussion

The maze game was used in a clinical trial at the JFK rehabilitation institute. The male stroke patient was in his fifties three months after the brain injury. His clinical condition was typical of a stroke patient at that stage after stroke: the left hemisphere of the brain was impaired, resulting in spasticity in his right hand. Although his left hand remained practically functional, the right side of his body had little freedom or range of motion. Occasionally, the patient used his left hand to reposition his right hand. The patient’s slight limp on the right side was further evidence of the neural damage.

During alpha testing of the Dynawheel applications, one major problem was encountered: the patient relied on trunk movements in addition to wrist movements to play the game. Because it is mostly repetitive wrist movement that bulwarks and propagates the neuron connections, the usage of the trunk instead of the wrist serves as a major obstacle to proper rehabilitation. The issue can be manually corrected if the therapist instructs the patient to not use his or her trunk movements. Programmatically, it may be corrected by incorporating a facial recognition algorithm (Figure 5) to the game which relies on the phone camera recording the patient’s eyes and ensuring they are not horizontal in the perspective of the camera when the Dynawheel is tilted. If the eyes are horizontal, it is likely that the patient is relying on a trunk movement to move both the Dynawheel and the whole upper body rather than using solely wrist movements.

![Image of facial recognition checks](image)

**Figure 5: Facial Recognition Checks**

The patient also relied much more heavily on one side of his body, as is typical of stroke victims. Because relying on the stronger side results in less exercise for the weaker side, therapists generally encourage bilateral exercise because it stimulates neuroplasticity. However, the flexible design of the Dynawheel also allows for unilateral exercise. After playing the game bilaterally, the therapist adjusted the Dynawheel, allowing the patient to hold the middle grip, so the game could be played unilaterally with the weaker hand. Although Dynawheel’s defining characteristic is its ability for symmetrical bilateral movement, the design of the Dynawheel as well as the usability of the Maze Race game also allows for unilateral training. The patient’s bilateral time was 57 seconds and the unilateral time
with using only the weaker right hand was 64 seconds (Figure 6).

**Figure 6:** Good Form (top) and Bad Form (bottom)

Due to the unreliability of Gideros Studio, internet connectivity issues at the rehabilitation clinic prevented proper testing of the Veggie Catcher game with an actual stroke victim. However, an emulator was run on the computer to simulate actual gameplay; the therapist, after reviewing the benefits and weaknesses of the game proposed to add different game selections: one version that involves gripping, one version that does not require gripping, one version that has vegetable resets, and one version that incorporates both challenges. The advantage of this system is that the game evolves along with the patient -- as the patient improves, the game can also progress to a higher difficulty to increase bilateral coordination. Also, the potential audience of stroke patients who can use this game multiplies. While some patients are able to grip the magnetometer, some are unable to release, and other patients have issues with both movements. The therapist is able to adjust game settings to accommodate the needs of both extremes.

The therapist also noted issues with the Dynawheel itself. Because the grips are not locked onto the Dynawheel and have a 360 degree freedom of rotation, it is difficult to play the game in a horizontal position. When it was revealed that newer editions of the Dynawheel lock the grip onto the Dynawheel and do not allow for unforced rotation, the therapist’s fears were alleviated.

In addition to motor skill discrepancies in patients, cognitive functions also differ depending on where the stroke is located in the brain. As the therapist noted, several patients had trouble focusing on a particular task for an extended period of time. Some needed to be coaxed to move onto new activities, demonstrating a typical disparity in levels of patient focus and displaying typical fluctuations in cognitive consequences as a result of stroke. The variability in patient needs makes it vital for versatility in game settings each session.
Conclusion

Both games have been successfully integrated with the Dynawheel. The applications are enjoyable, engaging, and aesthetically pleasing. The applications record the patient’s flexion, extension, deviation, and endurance time and compare the metrics to previous sessions. The maze game has 5 difficulty levels that are played sequentially. The Veggie Catcher game has 4 adjustable settings: grip, speed, vegetable reset, and time. This results in 32 different gameplay modes.

More customization options need to be added to the maze game. The Maze Race as well as the Veggie Catcher game need more complex levels for patients in later stages of rehabilitation. Eventually, some degree of randomness should be added to both games so they remain engaging for patients undergoing long term therapy.

More clinical trials are necessary for determining the effectiveness of the Dynawheel and the applications. The games must be compared in the long term against traditional therapy methods. Patients would be split into three groups: one receiving only Dynawheel-based therapy, one receiving only traditional therapy, and one receiving a mixture of Dynawheel and traditional therapy. The progress of patients should be tracked by the standardized National Institute of Health Stroke Scale (NIHSS) as well as with the Dynawheel's metrics, like grip strength, wrist range of motion for ulnar and radial deviation, and endurance time at max level. Final data that would be compared among the groups would include total recovery time necessary to reach a certain point in therapy. Three, Two-Sample T-Tests comparing the three subject groups would be conducted to test the significance of the Dynawheel when compared to already established methods.

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