The FLEX (Fine motor Learning and EXercise) Gamified Glove: Enhanced Occupational Therapy for Parkinson's Patients

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Abstract

Parkinson's disease is the second most common neurodegenerative disease in the United States, caused by the progressive loss of neurons, which decreases dopamine levels in the brain. Patients with Parkinson's experience both physical symptoms such as tremors and rigidity, and a decrease in cognitive function. Typical occupational therapy for Parkinson's patients includes working through fine motor rehabilitation exercises in sessions with an occupational therapist, followed by completing at-home exercises individually. These exercises are essential for patients to continue making progress in their rehabilitation therapies. Improvements in fine motor motion have also been correlated with improvements in cognitive function; therefore, by improving fine motor dexterity, patients can also improve cognitive symptoms. However, a key struggle for Parkinson's patients is maintaining motivation to complete their at-home exercises as many lose motivation/are discouraged after failing to see progress. As a result, people with Parkinson's need a way to add motivation to occupational therapy and view their gradual progress during rehabilitation therapies to maintain motivation for completion. A device referred to as the FLEX (Fine motor Learning and EXercise) glove has been developed and tested to increase patient motivation by pairing a pattern repetition game with daily rehabilitation exercises in order to improve cognitive function while tracking patient progress to display to both the patient and occupational therapist.

1.0 Introduction

More than 50 million people worldwide suffer from neurodegenerative diseases (Dimmer, 2024). While neurodegenerative diseases manifest differently in individuals, many neurodegenerative diseases are characterized by both symptoms of cognitive decline and physical decline, and nearly all eventually make completing activities of daily living (ADLs) difficult. In these cases, patients are often referred to an occupational therapist and instructed to complete rehabilitative exercises to improve their range of motion and strength. Strength, especially grip strength, is essential for activities of daily living (ADLs) such as eating and drinking (Liu, Chen, et al., 2018). In contrast, range of motion is necessary for ADLs that require upper-limb movement, such as dressing (Gates, Walters, et al., 2015). As these exercises are generally repetitive and routine, patients quickly lose motivation when they are unable to notice their gradual progress on a daily basis (B. Wike, personal communication, October 10, 2024). Addressing these motivational factors will be beneficial to both patients and caregivers.

1.1 Neurodegenerative Diseases

Neurodegenerative diseases are commonly associated with slow deterioration of the nervous system, specifically within the brain, including neuronal cell death and the loss of vital neuron subsets. The leading causes of neurodegenerative disease include age, genetics, environment, and medical history. As a result, these conditions are much more likely to develop in people 65 and older. The most common neurodegenerative diseases include dementia-type diseases (caused by neuron death in multiple areas of the brain), demyelinating diseases (characterized by the damage of myelin, which is the insulating layer that wraps around nerve cells), parkinsonism-type diseases (caused by damage to specific neurons connected to managing coordination and controlling muscle movements), and prion diseases (characterized by protein misfolding that results in terminal brain damage) (Cleveland Clinic, 2024).

Parkinson's Disease is the second most common neurodegenerative disease in the United States and affects more than 10 million people worldwide (Parkinson's Foundation, 2025). Some of the most common symptoms of Parkinson's include tremors, muscle stiffness, slow movement, balance and coordination issues, slowed mental processing, and memory decline (Cleveland Clinic, 2024).

Parkinson's Disease is caused by decreased dopamine levels in the brain, specifically in the basal ganglia and the frontal lobes. The frontal lobe is the area in the brain that organizes and recalls information (Queensland, 2024), and the basal ganglia is part of your brain that controls motor function (Young, 2023). The cerebellum works in tandem with the basal ganglia to control movement and coordination. The basal ganglia and cerebellum are connected through specialized areas of brain tissue. When dopamine levels are decreased in these areas, patients experience tremors, rigidity, and slowed movement (Mazzoni et al., 2012).

Research has also shown a connection between cognitive and physical improvements in Parkinson's patients, including enhanced verbal memory abilities and cognitive planning (Chen, Ringenbach, Albert, & Semken, 2014). For example, hand-dexterity improvements also improve cognitive function due to the cerebellum and basal ganglia's functional connection with the frontal lobe (Worschech, James, et. al., 2023).

Cognitive function is defined as the mental processes involved in reasoning, acquiring knowledge, and manipulating information (Kiely, 2014). It is enhanced through neuroplasticity (Greenwood, Parasuraman, 2010), which is defined as the functional and structural changes to the brain caused by external stimuli (Puderbaugh & Emmady, 2023). Promoting neuroplastic changes in patients enables them to increase cognitive function; the patient's brain learns to use a different pathway to respond to external stimuli or complete a task. For example, learning how to use an arm again after paralysis (Stroke Association, 2024) or learning to speak a new language (Thrive Community, 2023) both promote neuroplasticity.

1.2 Occupational Therapy

In occupational therapy for Parkinson's patients, therapists typically guide their patients through exercises that involve both gross and fine motor movements. Sessions typically include assessing patient progress, guiding patients through active and passive exercises, and assigning homework. A typical patient may have 1-2 occupational therapy (OT) sessions per week, with rehabilitative exercises to complete at home, to increase their finger range of motion. This will ultimately help them perform activities of daily living. While OTs ideally want to introduce new exercises and instructions during sessions, they often spend most of their time reassessing patient progress. Additionally, many patients struggle to maintain motivation between sessions because they lack the professional training and knowledge to recognize their gradual progress, which can cause them to feel discouraged, as they believe they are not making any progress (B. Wike, personal communication, October 10, 2024).

Rehabilitation exercises can be passive, where an external force, such as an occupational therapist (OT), stretches the fingers, or active, requiring the patient to control their own movement. Both have the potential to improve cognitive function by promoting neuroplasticity, but active exercises also enhance muscle strength (Flint Rehab, 2023).

One key focus in therapy for Parkinson's patients is improving range of motion in the metacarpophalangeal (MCP) joint of the hand, which is the main knuckle joint that allows the fingers flexion and extension (Parkinson Life Center, 2014). Flexion is the term for bending fingers inward towards the palm and extension is the term for moving the fingers away from the palm (Cleveland Clinic Anatomy, 2023).

1.3 Effects of Gamification on Motivation

Gamification refers to the use of game-like elements in non-game contexts to enhance motivation and engagement. Gamification enhances engagement in the activity, thereby increasing motivation to complete it, and is often employed by students to enhance their engagement in learning (Alsawaier, 2018). An example of gamification to increase learning engagement is language learning apps, such as Duolingo or Babbel. Aspects of a game that make it engaging to increase motivation include having a clear goal, immediate feedback, adaptability, rewards, and fun failure. Having a goal promotes voluntary participation, while immediate feedback and adapting the game based on the participant's mastery are shown to be more engaging for the participant. Fun failure refers to participants not worrying about failure because the game is repeatable, and rewards offer an incentive to continue playing the game (Luo, 2021). An example of fun failure is pattern repetition, which occurs due to the low-stakes repeatability and the incentive to continue playing until the pattern has been mastered or successfully repeated. Games and gamification have also been shown to aid cognitive function through increased motivation and stimulating environments, which promotes the development of new neural pathways (Dell'osso, Nardi, et al., 2024).

1.4 Literature Review

The Connection Between Hand Exercises and ADL Progress

In 2018, a study evaluated the effects of passive finger exercises on grip strength and activities of daily living (ADLs) in patients with dementia (Liu, Chen, et al., 2018). Although grip strength specifically did not improve, the patients demonstrated progress in activities of daily living (ADLs), including dressing, walking, and using the bathroom. Since improving the ability to complete ADLs is a key part of Parkinson's rehabilitation, this study supports hand exercises as an indirect form of ADL improvement. Although Alzheimer's and Parkinson's are neurologically different–Alzheimer's involving neuron death and Parkinson's involving dopamine loss and damage to specific neurons (Cleveland Clinic, 2024)–the ADL improvements in Alzheimer's patients in this study also reflect the expected recovery of Parkinson's patients.

The Effect of Motor Learning Feedback on Cognitive Functions in Parkinsonism

In 2022, El-Din Mahmoud conducted a study on two groups of patients with Parkinson's. One study group participated in motor learning feedback exercises and selected cognitive therapy, while the other group only completed selected cognitive therapy. The experimental group had an added task of learning and completing a step routine while completing cognitive tasks. Both groups demonstrated improvement in cognitive function; however, the experimental group showed significantly greater improvement (El-Din Mahmoud, 2022). The study shows that targeting the basal ganglia and activating fine motor movement has a motor-cognitive connection. Additionally, pattern repetition exercises, such as those completed by the experimental group, have also been shown to lead to cognitive improvements (Dell'Osso, Nardi, et al., 2024). Therefore, gamification through pattern repetition can also be assumed to have cognitive benefits.

Existing Products on the Market

A market study survey reveals that no existing products currently target both measurable finger flexibility and patient motivation through a gamified system as an occupational therapy aid. The closest products include a goniometric glove that measures the angular displacement of finger joints (Williams, Penrose, et al, 2000) and a glove-type device that controls the flexing of each finger with finger-attached pneumatic actuators (Tejada et al., 2024). The FLEX glove is unique in that it incorporates a memory gamification system to enhance patient motivation while also measuring range of motion to improve cognitive function.

1.5 Problem Statement

Most people with Parkinson's disease suffer from symptoms including tremors, rigidity, slowed movement, and cognitive decline, eventually affecting their ability to complete activities of daily living. As a result, they often need to work with occupational therapists to improve both strength and range of motion. However, sustained progress relies on the consistent completion of rehabilitation exercises at home—and without visible signs of progress, many patients lose motivation and stop completing their exercises. Thus, Parkinson's patients need a way to remain motivated while completing their rehabilitation exercises in order to increase their range of motion and cognitive ability, allowing them to perform activities of daily living.

To address this, the FLEX (Fine motor Learning and EXercise) glove was developed using flexion sensors to measure finger range of motion, along with the integration of a pattern memorization game. By incorporating a memory challenge and displaying progress over time, the device encourages patients to continue completing their exercises while simultaneously improving finger dexterity. Furthermore, the data collected by the glove device can help occupational therapists streamline tedious evaluations by allowing them to receive and review patient progress before their allotted time together.

2.0 Methods

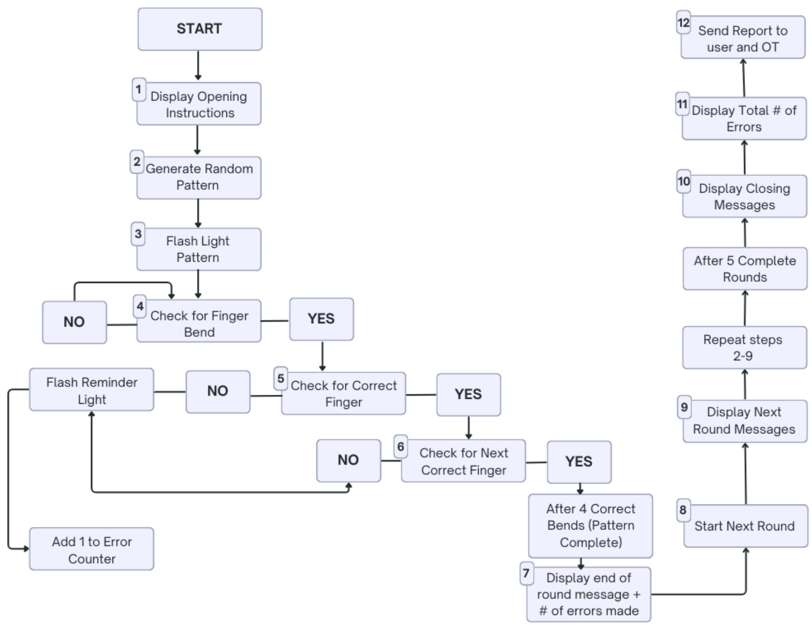
2.1 Hardware Development

The FLEX glove hardware consists of a comfortable knit glove with flexion sensors attached to the fingers, not including the thumb. Flexion sensors are thin, carbon ink sensors that change resistance based on the amount of flexion. These sensors cover the MCP joint of each finger, allowing detection of both downward flexion motion and return to straight. Each finger sensor is connected to one of 4 different colored lights (red, yellow, blue, and green). Additionally, a user interface panel displays game instructions and results, and a buzzer provides an alert sound system for the user.

2.2 Software Development

A threshold sensor value was determined via testing to distinguish between a bent and a straight finger. The software not only checks if the correct finger is bent, but it also ensures that *only* the correct finger is bent by checking that the values of the other three sensors remain above the threshold. A flowchart depicting the glove's full functionality is shown in **Figure 1**. To begin, the user must insert their hand into the glove and power on the device. Upon activation, instructional messages are displayed on the screen. A 4-colored light pattern is then displayed for the user to watch and replicate by bending individual fingers in the glove. As each finger is bent, the corresponding light turns on in response.

Figure 1: Full Software Flowchart



A correct movement triggers a confirmation message and alert tone, while an incorrect movement elicits a lower-pitched tone and an on-screen error message. The missed light is flashed again, allowing the user to try again without having to restart the entire sequence. This function was added to encourage users to complete the pattern all the way through, regardless of any errors they make along the way, thereby maintaining user motivation and reducing potential frustration throughout the game.

After each complete pattern, the screen displays end-of-round messages along with the number of errors made. This error counter was integrated to allow users to view their progress over time. After 5 rounds, the closing messages and total number of errors are shown.

2.3 Validation Process

To ensure that the FLEX glove was fully capable of meeting its functional requirements, users played through the full 5 rounds of the game multiple times to verify its functionality. Successfully functional is defined in **Figure 2**.

Figure 2: Success Criteria	
1)	Displays clear usage instructions when turned on
2)	Generates and displays a randomized light-based pattern for user replication
3)	Tracks user input and identifies deviations from pattern
4)	Monitors and detects finger flexion and extension through integrated sensors
5)	Displays a series of 5 sequential but random patterns per session for completion

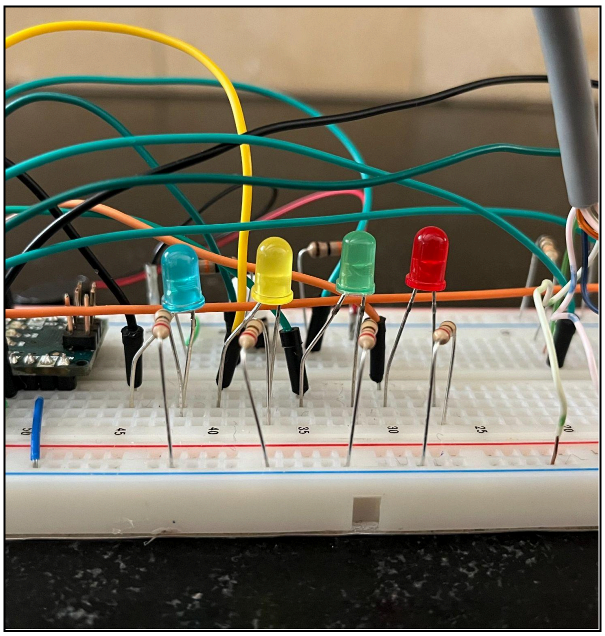
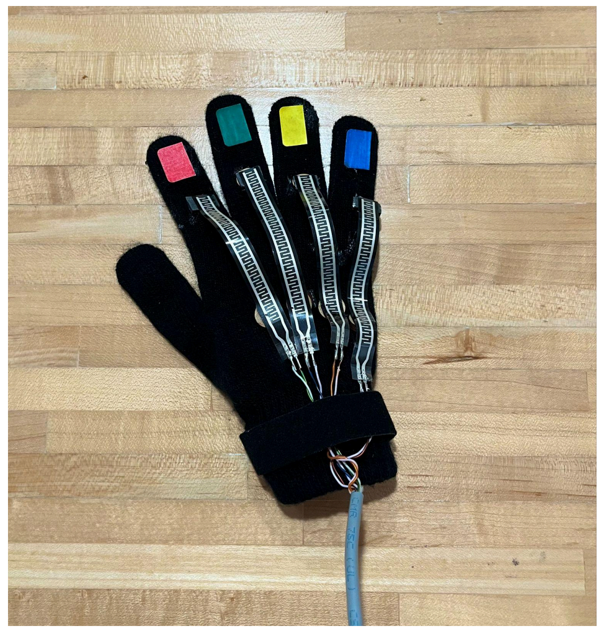
To validate the device with outside participants, success will be based on: 1) Clarity and Ease of Use, 2) Engagement and Enjoyment, and 3) Motivational Impact. Users will be presented with a usage report as part of their at-home exercises for occupational therapy to allow evaluation of the report for ease of understanding of the presented data.

2.4 Occupational Therapist and Patient Report

The occupational therapist and patient will receive individual emails after completing a session with the FLEX glove (5 rounds of patterns) containing a report of the session. Each report will include the consecutive days the patient used the device, the amount of time it took the patient to complete the game, the progress the patient has made over the past week, and the progress the patient had made in the session of the game they had just completed. Weekly progress will be tracked based on the number of days since the last OT session, and the progress made will be determined by the amount each finger was bent as a percentage of the maximum bend. For patients, the progress will be presented as the average amount bent for all fingers combined per day. For OTs, progress will be presented as the highest percentage bent for each individual finger per day. For the progress made in the most recently completed session, the patient and the OT will be presented with the maximum percent bend for each finger for each of the 5 completed patterns. The goal of the patient's report is to demonstrate the progress they are making by completing exercises with the FLEX glove.

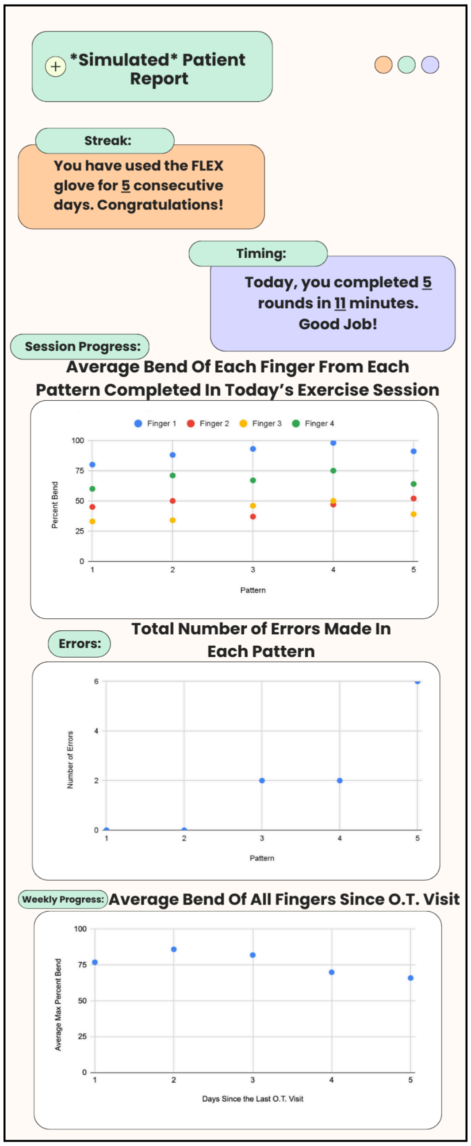
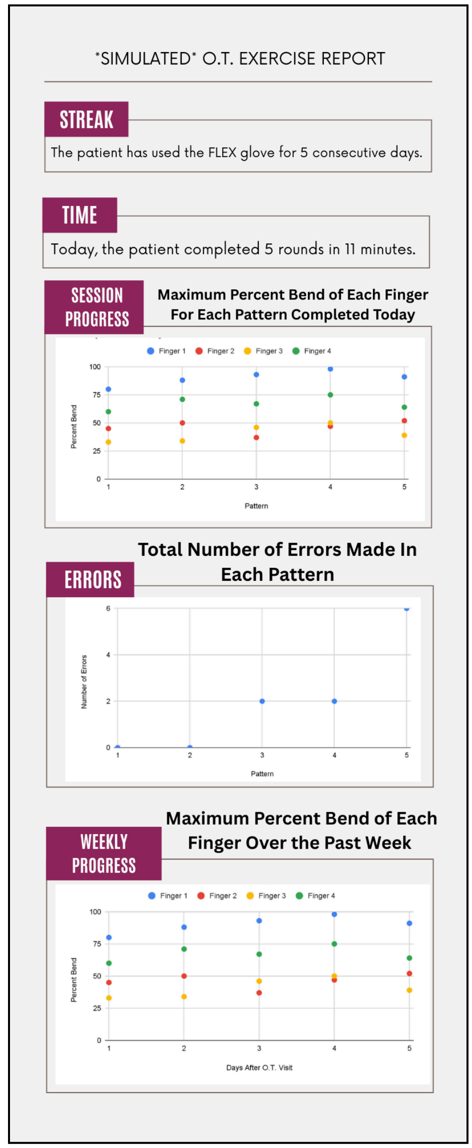
3.0 Results

To evaluate the FLEX glove's effectiveness, a self-validation process was conducted in which the development team completed 5 rounds of the game using the device. During the validation process, each success criteria shown in **Figure 2** was found to be fully functional. Across repeated trials, the glove demonstrated reliable performance of each function.

<table>
<tr><td colspan="2">Figure 3: Current FLEX glove prototype</td></tr>
<tr><td>Figure 3A: Four Colored LEDs</td><td>Figure 3B: Glove With Flexion Sensors On Four Fingers</td></tr>
<tr><td></td><td></td></tr>
</table>

The FLEX glove carbon ink sensors successfully detect the downward motion of the MCP joint for all 4 fingers on the hand that were intended to be detected. This detection of downward motion was successfully integrated with the completion of the 4-light pattern, and each of the sensors connected to one of the 4 lights was able to detect motion, allowing the pattern to continue. The buzzer was successfully incorporated into the game to signal when patients could start and when they made a mistake in repeating the pattern. The user interface display screen also clearly displayed user instructions to patients, as well as the total number of mistakes the patient had made.

Figure 4: Sample Reports for Patients and Occupational Therapists

Figure 4A: Simulated Patient Report	**Figure 4B:** Simulated Occupational Therapist Report
	

4.0 Discussion

The FLEX (Fine motor Learning and EXercise) glove, a fine-motor rehabilitation device paired with a memory repetition game, was designed and developed with the purpose of measuring patient progression of finger dexterity in Parkinson's patients and increasing their motivation to complete rehabilitation exercises at home, while simultaneously improving cognitive function. Given the success parameters described in **Figure 2**, the FLEX glove consistently displayed clear usage instructions and generated completely random light-based patterns without fail throughout the validation process.

As the FLEX glove was only self-validated by the development team, formal validation steps going forward would include presenting the prototype and simulated reports to an OT advisor, Dr. Beverly Wike, to receive constructive feedback and professional insight. Moreover, testing the glove with individuals aged 65 and over would help validate ease of use and ensure the device performs effectively with its intended user age group. In addition to formally validating the FLEX glove's performance, Phase 2 of the project includes plans to enhance the FLEX glove's functionality by incorporating the features illustrated in **Figure 5**.

Figure 5: Summary of potential FLEX glove enhancements

Stored Memory	Device could track data over multiple days/weeks
Extension Range Of Motion	FLEX could track extension (motion away from the palm) of the MCP joints
Automatic Patient/OT Report	Automatically generate reports from patient data to streamline data analysis
Timer	Track duration of each round + automatically turn device off when no movement is detected after long periods of time
Wireless Hardware	Attach the LEDs on the glove to eliminate excessive wires for easier usage/mobility
Stops between rounds	Add a function that gives the user the option to press the button after each completed pattern when they are ready to start the next round
Patient Calibration	Glove would establish a baseline for the patient using the device to increase personalization

5.0 Conclusion

Parkinson's disease is characterized by physical symptoms such as tremors and rigidity, and a decline in cognitive function. Patients with Parkinson's attend occupational therapy to mitigate their physical symptoms. Due to the interconnected basal ganglia, cerebellum, and frontal lobe, improving fine motor dexterity also enhances cognitive function for patients, making occupational therapy a crucial aspect of Parkinson's rehabilitation. Outside of sessions, OTs give patients at-home exercises to complete. Despite these benefits, patients struggle to maintain motivation because they cannot see the gradual progress they are making. Thus, patients needed a way to view the gradual progress outside of their rehabilitation sessions in order to maintain motivation to continue performing their at-home exercises. To address this, the FLEX glove was designed with the goal of enhancing motivation and engagement in completing at-home rehabilitation exercises outside of occupational therapy (OT) sessions. Gamification has been shown to increase motivation, which was incorporated into the FLEX glove through flashing light pattern repetition. Additionally, patients can see the progress they made through the error counter and the flexion sensor readings that display the amount the patient's fingers bent.

There is also a motor-cognitive connection between fine-motor movement improvement and improvement in cognitive function. By using the FLEX glove, patients can improve their motor function, which in turn enables them to enhance cognitive function through the fine motor exercises they perform while wearing the glove. Ultimately, the FLEX glove supports the ongoing progress of Parkinson's patients by increasing their motivation to complete at-home rehabilitation exercises, thereby closing the gap between therapy and recovery and allowing patients to look forward to a better future ahead.

In this project, AI tools were utilized to support the literature search and aid in software development. We would like to acknowledge and thank Ty Buxman and Bruce Waggoner for their patient guidance and constant assistance as advisors on this project, as well as Dr. Beverly Wike, OT, from the Pasadena Rehabilitation Institution, for sharing her extensive knowledge and expertise in treating patients with neurological impairments. This project would also not be possible without the resources and support provided by our school, Flintridge Sacred Heart Academy.

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7.0 Appendices

7.1 Link to FLEX glove Software

https://drive.google.com/drive/folders/1VxICgI_yMHWfZCVpLRUb3Cg4BSHxXLrG?usp=sharing

7.2 Market Study - Hand Rehabilitation Robot Gloves

Device	Cost	Utility	Unique Features	Limitations
SYREBO C10 Rehabilitation Glove	$329.00 ($330.00)	~soft robotics tech ~relieves muscle tension ~promotes brain and nerve recovery ~multiple sizes	~Mirror training ~Customizable training ~Ergonomic design ~Portable and user-friendly	~limited mobility for severe cases ~size limitations ~expensive
Saeboglove Hand Therapy Rehabilitation Glove	$349.00 ($350.00) (Saebo, 2024)	~Dynamic finger extensions ~ Lightweight and wearable	~Tension System - elastic bands ~Customizable tensions ~Daily Functionality ~Hand and	~Not good for severe spasticity ~Manual adjustments are required ~Restricted to specific injury types

			forearm support	~Durability (elastic bands)
ReGrasp Glove by Rehabtronics	$2,995 ($3,000.00) (*ReGrasp - Rehabtronics*, 2021)	~Functional electrical stimulation (FES) ~portable and rechargeable ~targets hand and finger movements	~electrical stimulation ~Customizable Therapy ~Discreet Control ~All-Day Wearability	~not suitable for patients w/ pacemakers, fractures, dislocations, cancer ~prescription required ~expensive price
Sammons Preston Traction Glove	$44.62 ($45.00)	~Adjustable resistance ~compact design ~finger and hand therapy	~Resistance from rubber bands ~very affordable	~limited to simple rehabilitative movements ~not good for severe spasticity ~no motorized assistance ~requires some hand mobility

7.3 Links to Glove Devices on the Market

SYREBO C10 Rehabilitation Glove:

https://syrebocare.com/products/syrebo-hand-therapy-rehabilitation-gloves-robot-stroke-hemiplegia-hand-training-equipment

Saeboglove Hand Therapy Rehabilitation Glove:

https://www.saebo.com/products/saeboglove

ReGrasp Glove by Rehabtronics:

https://rehabtronics.com/product/regrasp-rehabilitation-glove/

Sammons Preston Traction Glove:

https://www.amazon.com/Sammons-Preston-Rehabilitation-Exerciser-Increasing/dp/B002BUFPH0?th=1