ENGGEN 115 Principles of Engineering Design

Design Project 2 - 2018 S2

Hand Mounted Exoskeleton for Improving Post Stroke Physical Control

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Executive Summary

Worldwide, approximately 15 million people per year suffer from strokes. Of these 5 million die and 5 million are permanently disabled. Many stroke patients lose some neurological connections leading to paralysis. Neuroplasticity can bring back some motor skill. It occurs through repetitive exercise which forms new neural connections allowing the brain to recover lost functionality. However due to lack of physical activity after a stroke, muscle deterioration occurs. This causes patients to fatigue easily when basic motor skill has returned.

The purpose of this report is to use methods and materials that can produce a cheap, ergonomic and effective post-stroke device that will help to bring back the patients independence. The requirements to be met for the design were chosen and used to guide the conceptual design. The performance matrix used to evaluate the designs used heavier weighting for requirements of higher importance.

The final chosen design for post-stroke rehabilitation was the finger exoskeleton which consists of 5 separate parts all made from ABS plastic. A velcro strap connects each of the blocks to the fingers. These straps are lined with cotton. Rubber is used at the points the device touches the fingers for comfort. There are hinges connecting each of the separate blocks which allow the finger joints to move. The resistance of the hinges can be increased to make joint movement harder, hence exercising finger muscles.

1 Introduction

A stroke is caused by a sudden interruption of blood supply to the brain. Approximately 15 million people worldwide suffer from strokes per year. 5 million are left permanently disabled by them (StrokeCenter, 1997). Stroke victims often suffer from the loss of cognitive and motor functions. This causes a range of effects such as difficulty in communication, movement, awareness and control. 40% of stroke victims experience moderate to severe impairment, which requires long term care (Stroke, n.d). This care comes in the form of rehabilitation, which generally focuses on helping patients relearn skills that they may have lost due to brain damage (NHS, 2017). Recovery practices range from speech or language therapy that improves communication, to physical exercise and physiotherapy that improves movement and motor functions. The scope of this report covers the use of devices to aid in rehabilitation and life after stroke.

2 Project Objectives

After stroke onset some patients struggle with reduced muscle function. This is caused by areas of the brain responsible for movement becoming damaged. This prevents brain signals from being produced to command a muscle to move. During early rehab basic motor skills can be relearned as new connections are made in the brain to account for those lost. This process is called Neuroplasticity (ScienceDirect, n.d). However due to the decreased muscle use in early rehab, they become weaker and deteriorate. This causes fatigue in life after stroke (Stroke UK, 2013). The device should aid with repeated exercise of muscles in the fingers to restore their health. It must be low cost to make it accessible to all patients. It is suitable for adults as it should cover 95% of adult human finger sizes. The full bounding specifications are listed in the Product Design Specification (PDS) (Appendix A).

3 Model Development

After defining the project objectives, there were questions as to what different types of designs would be most effective. Inspiration was taken from existing designs (Figure 1.0)

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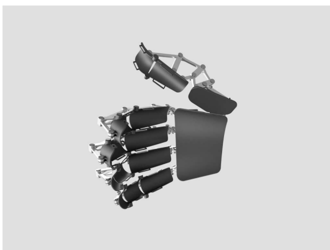
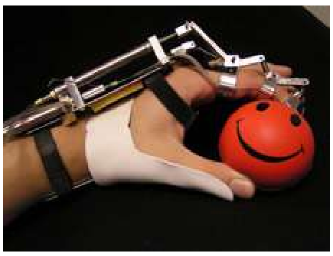
https://phys.org/news/2016-09-brain-robot.html



Retrieved from:
https://gallery.autodesk.com/fusion360/projects/hand-exoskeleton



Retrieved from:
http://neurobotics.cs.washington.edu/projects.html

(Figure 1.0) Different types of hand mounted device concepts already invented

A morphological analysis was performed to look at different ways of addressing the problem. Three concept designs were produced which meet the specifications established in the PDS (Appendix A). These three designs are the stress ball, electroshock glove and hand exoskeleton. Referring to the morphological analysis table (Appendix D), the red highlighted design features produced the hand exoskeleton design.

3.1 Factors influencing the design

The first factor considered was the stakeholders of our device. The PDS was designed to cater to most of the stakeholders, prioritising the patient and carer as they are impacted the most by the design. (Appendix E). The following physical constraints were devised to meet the patients needs. The designed device should have an ergonomic fit on the hand. To accomplish this, the size of the device may have to be adjustable in order to fit patients with different hand sizes (Appendix A, Physical constraints). The device should also have a lifespan of 5 years, which requires it to be durable. The patients are likely to have limited strength due to stroke, so the device should also be fairly light weight for ease of use.

The design should also adhere to any legal requirements and safety procedures in the countries/regions it will be released in (Appendix A, Legal requirements). The financial feasibility was also considered with a max materials cost of $100 (Appendix A, Financial Requirements).

3.2 Analysis of conceptual designs

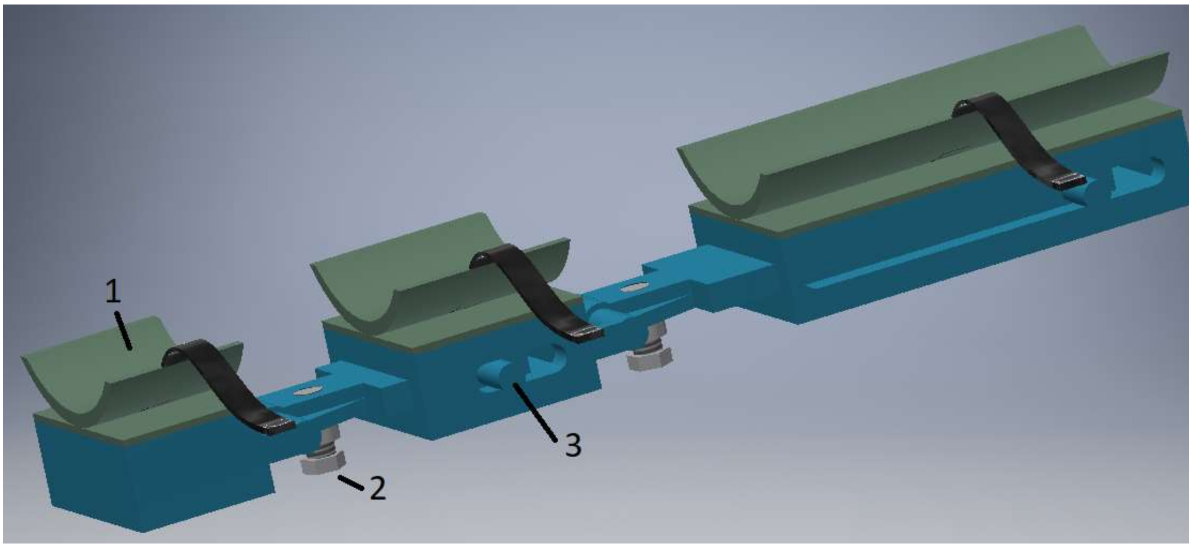
The three shortlisted conceptual designs were the Stress Ball, Electroshock Glove and the Hand Exoskeleton. A total of 7 factors were selected: cost, safety, comfortability, carer burden, independence, durability, adjustability.

To analyse and compare the designs, A weighting matrix was created to find out which criteria and features should be prioritised over others. After doing that, a performance matrix (Appendix C) was used to rate each design on a scale from 0 to 4, to determine which one was the most suitable to recommend.

4 Recommended Design

The final design recommended for a stroke patient who has lost muscle functionality due to muscle deterioration is the hand exoskeleton design. It was the most effective compared to the PDS and performance matrices.

The design is made up of ABS plastic, velcro, rubber and cotton fabric. These materials are low cost, which suits the production cost constraint. The revised design is made to only attach to the fingers. This is because the resistance is produced by the joints on the finger segments of the device. Therefore mounting it on the dorsum of the hand was no longer needed as shown in the initial design (Appendix F). This reduces the material cost, making it more accessible to the patient. It will cost $0.92 per unit to produce based off the material costs calculated (Appendix B). ABS Plastic is also strong, so can withstand any tension force it undergoes as the user extends and contracts the device (Plastics Int, n.d). As the design is made of 5 separate assemblies for each finger, it is compact and easy to transport. This also makes the device lightweight. Additionally, it makes the device usable with both hands, eliminating the need for separate left and right hand versions of the product.



(Figure 1.1) One finger assembly of the device

The device sits on the finger using the curved rubber mounts shown in green and is secured by velcro straps shown in black (Figure 1.1, annotation 1). The length of each finger assembly segment can adjust via sliding rails to fit a range of finger sizes (Figure 1.1, annotation 3). The hinges (Figure 1.1, annotation 2) are positioned over the finger joints, allowing the fingers to extend and contract. The screws in the hinges can tighten, increasing the friction in the hinges and thus the resistance to hinge movement. As the patients muscles get stronger, the resistance can be increased to cause the muscles to work harder, thus accelerating the exercising process. This exercise causes the muscles to regain health and become less easily fatigued.

5 Future Work

The design would benefit from future revisions to make it easier to use. Tests should be conducted to find out the coefficient of friction between the ABS plastic surfaces of the hinges.

Some of the hinges had to be made with different dimensions to accommodate for different finger sizes. After finding the ABS friction force, the next step would be to find the level of tightness for the different hinges that would create the same friction force.

Dials could then be printed onto each hinge to display the amount of resistance the screw produces.

Testing of the device's durability is important. The joints should be tested for wear and tear to ensure sufficient resistance is maintained throughout the 5 year life cycle. The effect of joint tightening on the ABS plastic (e.g. bending) should be investigated to ensure there is no permanent deformation.

Once the design has been revised it should be tested in a trial on stroke outpatients who have recovered basic motor skill. The design can be further revised based on feedback from this.

6 Conclusions

Focusing on outpatient rehabilitation, the goal is to encourage independence. This can be achieved by repetitive exercises to rebuild deteriorated muscle resulting from a stroke. To help achieve this goal, a performance matrix was used to develop the design to fit the constraints defined in the PDS.

Final Exoskeleton design:

- To be used independently with ease
- Design is affordable for the patients - $0.92 in material costs
- Lightweight
- Adjustable resistance due to friction between the hinges
- Adjustable for different finger sizes
- Device connects to fingers with velcro straps.

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8 Appendices

Appendix A - Product Design Specification

Product Identification:

- Help patient regain strength in hands
- Fits to a range of different sized hands

Special Features:

- Utilizes methods of strengthening muscles e.g. electric stimulation, exercise
- Lightweight

Key Performance Targets:

- To be independently used
- Appropriate for use after rehabilitation

User training:

- Carer should assist with initial set-up of device.
- User needs to know how to put it on
- Once set up, aid may be needed to set up for use e.g. family member. This will be infrequent and take minimal time.

Service Environment:

- Anywhere, preferably in a home environment
- Recommended that user has a stable platform to lean on or place their elbow.

Key Project Deadlines:

- 11th September, 2018 - Problem Statement Submission
- 11th September, 2018 - Draft PDS
- 24th September, 2018 - Report and drawing Submission
- 25th September, 2018 - Oral presentation and workbook peer assessment

Physical Description:

- Hand mounted device
- Colour of choice ROYGBIV
- Fits to the hand. Mounting options: Glove or Velcro straps

Physical constraints:

- Finger length range fits 95% of the population (measurements in mm) (Scielo, n.d):
    - Thumb - 53.24±4.73
    - Index - 77.98±9.71
    - Middle - 88.36±8.66
    - Ring - 84.32±9.38
    - Pinky - 66.81±7.76

- Mass ≤ 500g

Market Identification:
- Post - stroke outpatients
- Aimed at adults, due to hand size constraints
- Competing products include:
  - Saebo product range includes electro shock stimulating gloves and exoskeletons with gloves utilized for mounting. Price is not under $100 (Saebo, n.d).
  - The Rehab-Robotics Hand of Hope is an exoskeleton with motors that detects weak brain signals and assists with the desired and movements. Currently unaffordable to most (rehab-robotics, n.d).
  - The Rapael Smart Glove provides no assistance with movement but uses sensors to track the patient's hand movements, allowing them to play computer games designed to encourage certain movements. (neofect, n.d)

Manufacturing Specification
- Designed and manufactured in New Zealand
  Materials: TBD
- Supplies: TBD

Financial Requirements:
- Materials cost below $100.00 per unit
- Gross margin estimate of 50%
- Cost of Good Sold less that 20%
- Warranty period 2 years
- Capital investment: TBD

Life cycle targets:
- Life cycle >= 5 years
- Maintenance Schedule: No maintenance is required if taken care of
- Reliability: 5 years
- End of life strategy: Easily Recyclable

Legal Requirements:
- CE compliance for Europe
- ISO 13485 - Medical devices - Quality management systems
- ISO 14971 - Application of risk management to medical devices
- No planned US market release

Appendix B - Material cost calculations

ABS Plastic:
ABS plastic costs $28 per kg in New Zealand (3D Printing Services, 2017)
Mass of ABS plastic obtained from CAD model = 0.023kg

$$\frac{\$28}{kg} \times 0.023kg \ = \ \$0.644$$

Rubber:
Costs $2.54 per kg using May 2018 Singapore commodity exchange data (Statista, n.d)
Mass of Rubber obtained from CAD model = 0.005kg

$$\frac{\$2.54}{kg} \times 0.005kg \ = \ \$0.0127$$

Velcro:
Costs $12.50 for 11000x10mm in New Zealand (Zelfast, 2014)
Therefore $12.50 for 110000mm^2
Velcro straps are 30mm long based off average finger width of 20mm (Smashing Magazine, 2006) and are 5mm in width.
There are 14 velcro strips required therefore the total area required is:

$$14 \times 30 \times 5 = 2100mm^2$$

The cost is therefore:

$$\frac{\$12.50}{110000mm^2} \times 2100mm^2 = \$0.239$$

Cotton:
Costs $6.79 for 500x1600mm (800000mm^2) (AliExpress, n.d)
Same area of cotton required as Velcro (2100mm^2) therefore:

$$\frac{\$6.79}{800000mm^2} \times 2100mm^2 = \$0.0178$$

Total Material Cost:

$$0.644 + 0.0127 + 0.239 + 0.0178 = 0.9135$$

Total rounded up to whole cents = $0.92

Appendix C - Decision Matrices

Weighting Matrix

	Cost	Safety	Comfortability	Carer burden	Independence	Durability	Adjust-ability	Total Weight
Cost	-	0	1	1	2	2	1	7
Safety	2	-	2	2	1	2	1	10
Comfortability	1	0	-	1	0	1	0	3
Carer burden	1	0	1	-	1	0	1	4
Independence	0	1	2	1	-	2	1	7
Durability	0	0	1	2	0	-	0	3
Adjustability	1	1	2	1	1	2	-	8

Performance Matrix

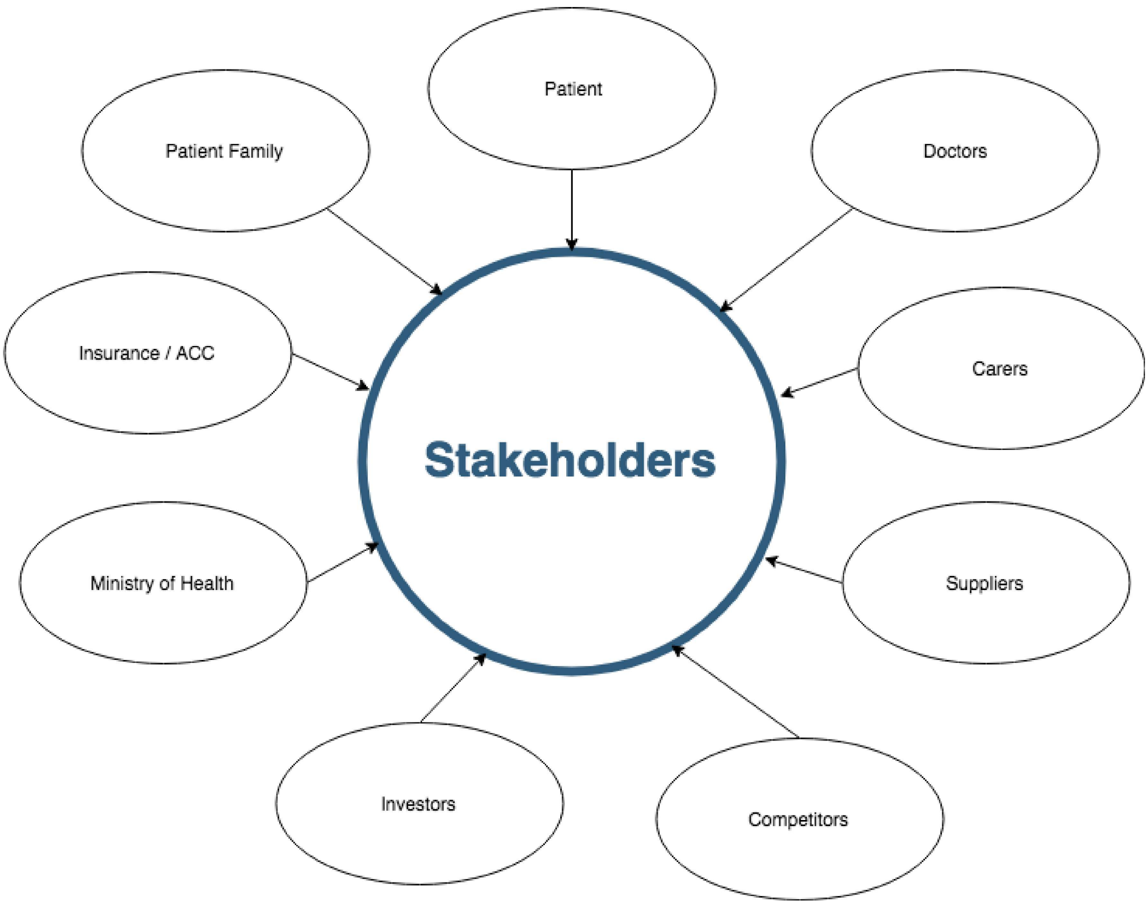
		Electroshock Glove		**Stress Ball**		**Hand Exoskeleton**	
Valuation Criteria	**Weighting Factor**	**Value**	**Value x weight**	**Value**	**Value x weight**	**Value**	**Value x weight**
Cost	7	2	14	4	28	3	21
Safety	10	1	10	4	40	4	40
Comfortability	3	3	9	4	12	2	6
Carer Burden	4	1	4	2	8	3	12
Independence	7	1	7	1	7	3	21
Durability	3	2	6	1	3	4	12
Adjustability	8	4	32	0	0	4	32
Total			82		98		144

How well it fits the criteria				
Not met		sufficient		excellent
0	1	2	3	4

Appendix D - Morphological Analysis

Feature	Solutions		
Power Source	Petrol	Electrical battery	No power
Joints	Hinges	Rubber	Motorised
Design Types	Glove	Exoskeleton	Stress ball
Material (body)	ABS plastic	Natural Rubber	Cotton
Size Adjustability	Not Adjustable	Sliding Joints	Elastic
Hand Mounting	Velcro	Glove	Clasps
Mounting Position	Top of hand	Bottom of hand	Surround hand
Resistance	Friction	Motor	Magnets

Appendix E - Stakeholder Diagram



Appendix F - Original Design