Final Design Report

RotaSense

Prepared for:

Dr. Kate Enzler
Alexian Brothers Rehabilitation Hospital
Elk Grove Village, Illinois.

Date:

March 11, 2023

Submitted by:

Madeline Demm, Andrew Li, Nikola Maruszewski, Kathryn Welch
Section 1, Team 1

Sponsored By:

Design Thinking and Communication Program
Professors Stacy Wolcott and Laura Pigozzi
McCormick School of Engineering and Applied Science
Northwestern University
Evanston, Illinois 60208

Is the Kate Enzler stuf
correct?

Make sure all names ar
spelled correctly.

Todo list

Contents

Chapter 1

Introduction

1.1 Executive Summary

Patients who have suffered from a stroke or a traumatic brain injury can develop a condition called left side neglect, which is the inability of the right side of the brain to process information that comes from the left side of the body and can cause the patient to forget that there is a whole world to their left side. Dr. Kate Enzler, a physical therapist at the Alexian Brothers Rehabilitation Hospital, works with patients who have left neglect and has found that current solutions for treating left neglect are not entirely feasible for daily use. Our class was tasked with designing a device that could remind patients to scan to their left in order to aid in the rehabilitation process. To approach this challenge, we conducted research on current solutions to left neglect and interviewed Dr. Enzler to gain further insight into the usefulness of these solutions, which allowed us to come up with three mockups. However, after user testing, it was found that different solutions worked best in different contexts, so it was decided as a class that each team would design a component of a greater "take-home kit" solution that could provide a more thorough approach to the rehabilitation process. Our component is a feedback device that is housed on a glasses strap and can track how far the user has turned their head. The major components of our device include an accelerometer gyroscope, which is able to track head movements, and an ESP-32 microcontroller, which is able to process the data collected by the gyroscope and send it via bluetooth to the other team's components. The major benefit of this device is that it allows for the personalization of the take-home kit; by tracking the user's head movements, the stimuli from the glasses and haptic clip can be adjusted to turn on when the user needs to scan left and turn off once the user has succeeded in looking all the way to their left. Therefore, this device helps to meet the solution requirements of customizability and adjustability, and its compactness also meets the requirement of wearability. Looking at future development of the design, one improvement that can be made is to refine the electronics with a custom printed circuit board so that they take up even less surface area. In addition, the angle-determination algorithm used by the device could be refined to make it more accurate.

1.2 Introduction

Better name

Patients who have suffered from a stroke or a traumatic brain injury can develop a condition called left side neglect. This condition is caused by the inability of the right side of the brain to process information that comes from the left side of the body. Patients therefore struggle to engage with the left side of their body (see Appendix B). This project specifically addresses the patients who struggle to continue turning their head past the midline of the body. Our project partner, physical therapist Dr. Kate Enzler, stated during the client interview that the typical patient often forgets there is a whole world to the left side of the body. This lack of head rotation poses everyday challenges for the patient, as they may bump into things on the left side of them, miss information when reading, etc. (see Appendix D). The solution to this problem is preferably wearable as per our client's request. Since left neglect patients span a wide demographic, the solution must be customizable not only to fit differently sized patients, but to also work for patients with varying degrees of left neglect (see Appendix A).

The research phase of this project consisted of both primary and secondary research. While researching the condition of left neglect, we also researched existing solutions for the condition and their shortcomings in order to avoid those elements in our design. Current methods of treatment include neck vibration therapy, prism therapy, eye patching, optokinetic stimulation, and the use of tangible stimuli to remind a patient to visually scan left. Many of these visual stimuli are effective short-term but do not have lasting long-term effects. Additionally, many of the products, despite being effective, required a lot of work with the therapist in order to understand how the device worked or what its purpose was. Many of these solutions also create a reliance on the patients' caregivers, limiting patient autonomy (see Appendix B). The goal of the product that we designed was to aid patients in regaining their autonomy while continuing to receive cues as a reminder to visually scan left. Our solution is a haptic motor clip that attaches onto a patient's hat or shirt, to a point of skin contact on the right side of their body, which serves as a haptic stimulus to remind the patient to visually scan left. The motor will connect via bluetooth to an app, which will control the motor. The final part of the solution will consist of a pair of glasses that have cue lines on the left side that guide the patients towards the left. The glasses also have a gyroscope on them that track motion and will communicate with the app, and turn the motor and lights off when the patient has turned their head to a certain degree.

Prior to the design review, every team partook in their own separate design process. All teams initially faced the same overarching challenge of designing a device for patients with left neglect that will remind them to scan left. Prompted with this question, every team delved into their own individual secondary background research (see Appendix B) and presented differing questions to Dr. Kate Enzler during the client interview to gain more insight on the problem (see Appendix D). After this interview with Dr. Enzler, the teams began ideating and creating mockups that resulted in some general similarities such as adjustable settings, a combination of audible, visible, and physical haptic feedback, and an app that can control such feedback. All the team's prototypes were then brought to user observation, where the teams learned what aspects of their prototypes did or did not function ideally (see Appendix E). It was at the design review that the entire section realized all teams had versions of the same general prototype idea (see Figure 1.1). Through this realization, we collectively decided upon assigning each team to oversee and create one design to eventually combine all four separate designs into one system rather than presenting four versions of the same design to the client.

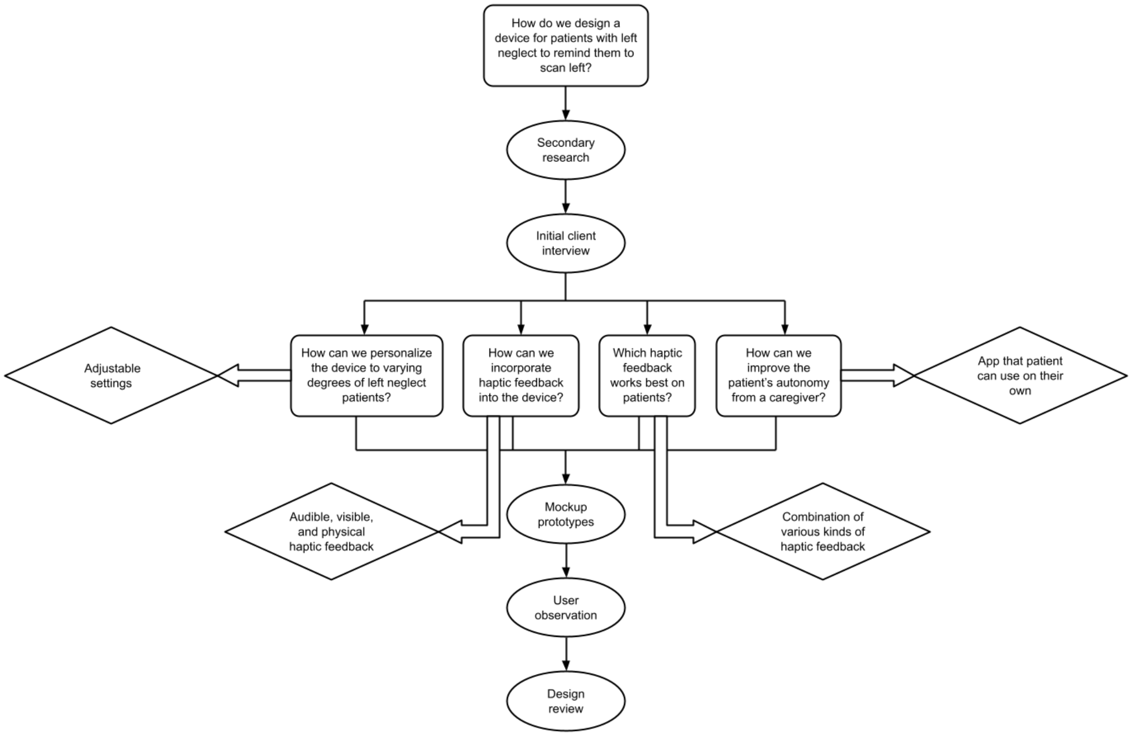

Figure 1.1: Flowchart that steps through a general design process all teams went through prior to the design review.

1.3 Design Requirement Status

Each of the products individually serve a greater purpose to fulfill the design requirements our product partner provided. The greater design requirements are as follows; Produce a product that is durable, simple, and affordable, that reminds a patient with left neglect to scan to the left. With our original individual groups we were struggling to provide for the full design requirements but as a collective with four different roles we were able to effectively meet each major requirement. The individual components of the product include a pair of glasses, a feedback device, a clip, and an app. Each team has been assigned one component to work on for the remainder of the project but all the components work together in order to create one product that meets all the requirements. The Glasses team was able to meet the requirement of having a reminder to help the patients look left. The lights on the glasses serve as a constant visual reminder for those wearing the device.

This paired with the haptics provide a range of stimuli to remind the user as the haptics headband works to also fulfill the same design requirement. These two components together fulfill the most important part of the design requirements and provide a solid base for the rest of the components to build upon.

Next comes the gyroscope which will be taking the data from the two reminding components and relaying it to the final component, the app. This helps to keep the project simple and adaptable so the user can track their progress and determine if the product is helping with their left neglect. This feedback is crucial to determining the efficacy of the project. The app works in tandem with the gyroscope to take in the data from the patient and provide a simple and usable interface to interact with.

All of these components help together to assist the patient with scanning left and provides them with feedback on the progress from their time using the product (see Figure 1.2).

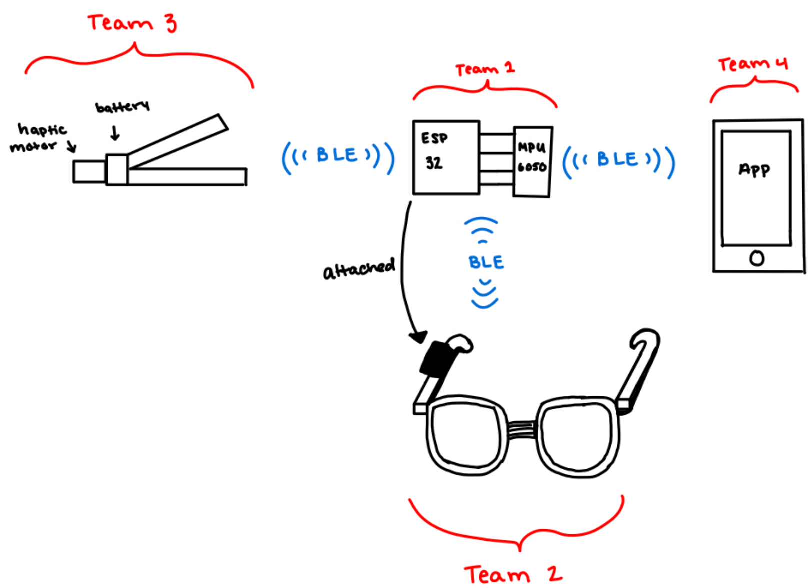

Figure 1.2: Integration diagram that shows how each component works together and which teams are involved in what parts.

Chapter 2

Users and Requirements

2.1 Main Users of the Design

2.1.1 Adults who are experiencing Left-Side Neglect

The users for our design will be patients at the Alexian Brothers Rehabilitation Center who have suffered a brain injury leaving them with inattentiveness to the left side of their body and surroundings. They need cues and reminders from a caretaker in order to remember to continue turning their head all the way to the left past the midline. They would like a solution that is easy to use and that reduces reliance on a caretaker in order to create more autonomy for the patient.

2.1.2 Physical therapists at Alexian Brothers Rehabilitation Center

The physical therapists work closely with the users to help them recover from their stroke and teach them techniques to mitigate the effects of left neglect.

2.2 Requirements

We identified the following requirements during the course of the quarter. The design had to satisfy each of them.

2.2.1 Lightweight

The device will be attached to a pair of glasses and therefore must be light enough to comfortably fit on the glasses and not put too much weight on the patient. It must be small enough to fit onto the glasses and not make them lopsided.

2.2.2 Durable

Since the device is attached to the glasses that will be worn frequently by the user, the device must be able to endure being worn daily as well as have a long battery life. The device must have some protective covering so that the patient is able to wear the glasses outside and so that the device can withstand being dropped from a reasonable height.

2.2.3 Customizable and Adjustable

The degree of left neglect and the most effective stimuli can vary between users. Thus, the device should facilitate the customizability of the stimuli provided by the other components of the take home kit.

Chapter 3

Design Concept and Rationale

The *RotaSense* is a device that can track the degree to which the user turns their head and relay this data to the other components of the take-home kit. The *RotaSense* is intended to be mounted on the *Blinky* (the glasses), and sends data to *LeftAware* (the mobile app), the *Blinky* and the *TheraPulse* (the haptic clip). The design has an accelerometer gyroscope that is able to track how far and how quickly the user is turning their head. This data is processed by the ESP32 microcontroller, and then relayed to the other components using the communication protocols.

The following sections describe the components of the device — accelerometer/gyroscope, ESP32 microcontroller, and communication protocols — as well as the rationale for each component.

3.1 Accelerometer/Gyroscope

When creating this device, we needed some way of tracking movement and some way of processing the movement data and communicating it with the app. In order to track the users' movement, we decided to use a MPU6050 Six-Axis Gyroscope and Accelerometer. This device was chosen due to its simplicity, affordability, and library support.

The MPU6050 is a commonly used gyroscope/accelerometer. It features high resolution motion tracking with a built-in Digital Motion Processor to allow for high-resolution data capture ($\pm 2g$) with data-processing on chip. This allows us to capture high-quality head position data with minimal power draw and computing resources on the microcontroller. The MPU6050 is also very small (smaller than a fingernail), lightweight (less than 5 g), and affordable (costing around $3 for a development board). And most importantly, it is a very easy to use device with excellent library support through I2CDevLib on the Arduino framework, allowing us to quickly prototype, test, and iterate on our design.

3.2 ESP32 Microcontroller

For communication purposes, we decided to use the ESP32 microcontroller from Espressif Systems. This microcontroller is relatively small, with a length of 48 mm, a width of 25 mm, and a height of 11 mm. It supports Bluetooth 5.0 (Low Energy) and the I^2C communication protocol, which are needed for talking to the phone and MPU6050 (section 3.1), respectively. It has two cores that

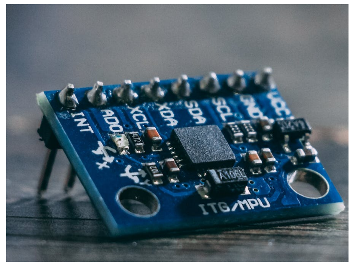

Figure 3.1: The MPU6050 Accelerometer and Gyroscope.

can run at up to 240 MHz, a deep sleep mode for extremely low power consumption, and a large online support base to allow for easy development. The chip is powerful enough to run a lightweight operating system, so we are able to use multiple processes to speed up computation and also save energy.

Figure 3.2: The ESP32 Microcontroller.

3.3 Communication Protocols

One of the most important components of our design are the communication protocols.

The I2C communication protocol was chosen due to its simplicity and unobtrusiveness, requiring only four wires for inter-device communication. It is a synchronous[1] serial[2] communication protocol, widely used for attaching low-speed peripheral devices (chips) to a controller chip for short-distance communication. Used widely throughout the industry, it has great library and device support, with no downsides.

Bluetooth Low-Energy was chosen for its lower energy consumption, as our device should be able to run for long periods of time while on battery power. While Bluetooth Low-Energy is a more complex system to work with, introducing more moving "parts" and slightly slowing down our iteration speed, as power consumption is a main requirement of our design, we felt it was a fair trade-off.

In the same vein of saving energy, we also will try to use the Deep Sleep mode of the ESP32 to reduce power consumption during idle periods to only 5 µW.

[1] All devices agrees on when messages are sent.
[2] Only one message is sent at a time.

Chapter 4

Future Steps

There are four directions for future development with regards to *RotaSense* and *Neglect No More* as a whole: app, data processing, electronics, and angle detection.

4.1 App Improvements

The app can be improved in three ways. One, some of the user interface design can be refined to be more user friendly, as some parts of the design can be confusing, especially for users who are less tech savvy. This improvement is quite straightforward, and requires rethinking some components of the design.

Secondly, and much more importantly, the account system needs to be rethought completely. Given that this app is a healthcare app, having an account system would require us to process data in accordance with HIPAA laws, which themselves are bundles of red tape. Though, for the sake of patient privacy, these laws ought to be respected. Having an account system means there is an increased chance of patient data leakage. The account system needs to be redesigned to eliminate this possibility, as otherwise there is a lot of grounds for legal action.

Lastly, the app can be set up to connect with Bluetooth. Due to constraints with Apple development, integrating the prototype app with Bluetooth would require a $100 Apple Developer License, which exceeds this project's budget. Instead, we created a Python proof of concept which works on a computer. While this is an okay substitute for now, it is not user-friendly as it requires extensive technical knowledge, making this a huge step for future development. Future development specifically can be done through using the user's phone's native Bluetooth library to interact with the microcontroller, which is a process that adds multiple layers[1] of programming on top of what is already complex for a prototype project.

4.2 Data Processing Improvements

The next direction for future development would be to improve the data processing. As of now, data is sent from the gyroscope microcontroller to the app by creating a ten-number packet (yaw, pitch, roll, acceleration in all three axes, gyroscope movement in all three axes, time). This can

[1] CocoaPods and Swift for iOS, Kotlin for Android, etc.

be potentially improved by doing more data preprocessing on the microcontroller through applying things like the Fourier transform. More research is needed to decide the best form of data to transmit between controller and device as well as whether a change is necessary.

4.3 Electronic Components

The electronic components must be refined from the current prototypical form. The current microcontroller-gyroscope system takes up a lot of surface area, and this can be reduced. Reduction of surface area can be done by printing a custom circuit board, which is not overly expensive or complicated. This, however, would only be economically feasible if this product were to be mass produced.

4.4 Angle Determination Algorithm

The angle-determination algorithm can be refined to be more accurate. Currently, the user will calibrate a gyroscope by using their mobile device, and any subsequent movement will be detected as a movement. However, if the user were to change positions, the gyroscope would need to be re-calibrated altogether. A previous idea was to have two gyroscopes, one on the user's chest area and one on their head, and the difference in angle is the angle of head rotation. Further research needs to be done to determine which angle determination mechanism is the most effective and least intrusive for the patient.

4.5 Future Steps Conclusion

The overall next step is to revise the current design to better promote user autonomy while preserving user privacy. These four ways are not extensive, but are the next steps with regards to improving *RotaSense* and *Neglect No More*.

Chapter 5

Conclusion

To summarize, our design and its function in the larger class solution meet the key needs of the users. The key components of our design are as follows:

- An accelerometer/gyroscope sensor that is capable of tracking the head movements of the user.
- An ESP32 microcontroller that provides bluetooth capability, allowing the design to communicate information on the user's head movements to the mobile application and haptic clip.
- Communication protocols that allow for high speed and low energy communication with the other teams' components.

The users need a solution that is customizable and adjustable, and the feedback component provides this by collecting information on the user's movements so that the stimuli from the glasses and haptic clip can be modified to make sure the user is looking completely to their left. In addition, it was required that the solution be lightweight and ideally wearable, and the design meets this need because it is small enough to fit on a glasses strap and the prototype weighs less than 100 g. Lastly, it was important that the solution be affordable, and our design is affordable, as the prototype can be built for a total cost of $28.

Appendix A

Project Definition

A.1 Document Information

Project Name RotaSense

Client Dr. Kate Enzler, physical therapist at Alexian Rehab Hospital (in partnership with Shirley Ryan AbilityLab)

Team Members Maddie, Andrew, Nikola, Kathryn

Date 02/14/2023

Version 3

A.2 Project Information

A.2.1 Mission Statement

Design a simple, lightweight, and adjustable device for daily use by individuals experiencing left-neglect to draw focus to the user's left side, enhance user autonomy, and improve general quality of life.

A.2.2 Project Deliverables

The end result of our project will be

- A final prototype.
- A final report.
- A final presentation in the form of a poster.

A.2.3 Constraints

We have two main constraints on this DTC project, namely time (10 weeks) and budget ($100).

A.3 User Information

A.3.1 Users and Stakeholders

The users and stakeholders for our project are

- People who are experiencing left side neglect.
- Therapists who work with patients on mitigating the effects of left side neglect.
- Family members/caregivers who are responsible for reminding the patients to look left at home.

A.3.2 Illustrative User Scenario

The user in the illustrative scenario below is based on an observation of a patient in therapy for left-neglect and supported by details from an interview with Dr. Kate Enzler.

The user begins their therapy session with Dr. Enzler at the Alexian Rehab Hospital. The patient has very recently had a stroke, and their eyes tend to look to the right side. When asked to perform the lighthouse scanning technique (a technique prompts someone to turn their head completely from right to left like a lighthouse), the user initially does not turn their head to the left, stopping instead at the midline. The user only continues scanning to the left when given a verbal cue by Dr. Enzler. There are people on the user's left, but the user only makes eye contact with the people in front and to the right of them. Dr. Enzler then puts up a finger on the user's left side, and the user is insistent that there is no finger there, assuming that Dr. Enzler is tricking them and believing that they have turned their head as far left as possible.

A.4 Project Requirements

Needs	Metrics	Units	Ideal Value	Allowable Value
Lightweight	Weight	g	Less than 25 g	Less than 50 g
	Max Size	cm	Size of an average pair of glasses	Average width of a human body
Durable	Lifespan	Years	Around 2 year	Around 1 years
	Battery Life	Months	More than 3 months	More than 1 month
	Element-resistant	N/A	Yes	Yes
Affordable	Price	Dollars	Less than $50	Less than $100

Appendix B

Background Research

At the start of our project, we conducted background research on terms, concepts, and conditions mentioned by our client, Dr. Kate Enzler from the Alexian Rehab Hospital, in her request for a design for something to alleviate left neglect. Left neglect is a neurological condition wherein patients have decreased response to their left sides, a condition our team has no background on. Our background research helped us understand left neglect, its severity, and current solutions to give us foundational knowledge needed for creating an effective design. This research was separated into three main sections: (1) defining left neglect, (2) understanding struggles patients with left neglect face, and (3) reviewing current approaches to left neglect.

B.1 Defining left neglect

Left neglect is a type of unilateral spatial neglect (USN), a syndrome that occurs after brain hemisphere damage [1]. Literature suggests that left neglect is more severe than right neglect [1], as well as 71% more frequent[2]. While left and right USN are both common after stroke [1], this higher frequency makes it more important to address left neglect due to its prevalence.

Literature also suggests that certain deficiencies are more severe for patients with left neglect. Peripersonal and extrapersonal neglect (neglect of one's personal space and neglect of one's immediate surroundings respectively) were found to be more frequent for patients with left neglect [1]. While right neglect also leads to deficiencies such as poorer balance [1], these left-dsided deficiencies highlight the need for something to alleviate left neglect. Figure B.1 depicts the difference in brain response to stimuli for patients with no USN, right USN, and left USN.

B.2 Understanding struggles patients with left neglect face

Patients experiencing left neglect have a reduced ability to interact with the left side of their perceived world. Figure B.2, below, compares the interactions of patients with USN to patients without USN.

Figure B.3 further illustrates patients' reduced interaction with their left side. In Figure B.3, it's critical to note that patients don't entirely neglect one side. The clock in Figure B.3.C for example has a left half and only lacks numbers on the left. This indicates that, while patients are

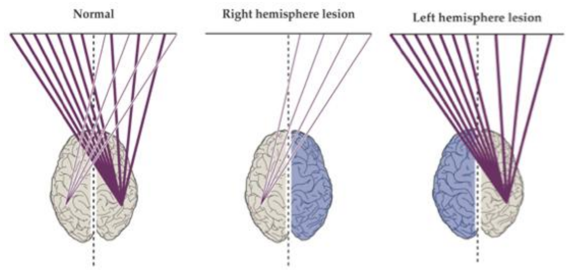

Figure B.1: Diagram illustrating the effect of both left and right unilateral spatial neglect on neurological response to stimuli on both sides of the brain [2]. Here, right neglect is shown to eliminate left-side brain interactions while left neglect still has some interaction with both sides. This implies that right neglect is more severe, making it substantially more difficult to address than left neglect. This key difference also implies that a solution to left or right neglect is not a universal solution to unilateral spatial neglect; such a universal solution would require further research, planning, and resources.

less aware of their left side, they aren't entirely unaware, but rather need reminders to interact with this neglected side.

However, this still depicts reduced interaction. When doing less-trivial tasks, such as eating, this reduced interaction leads to immense struggle with common daily tasks such as only eating the right half of one's food, shown in Figure B.4.

B.2.1 Types of Left Neglect

The types of neglect faced by those with left USN can be broadly split into four groups of neglect: personal, peripersonal, extrapersonal, and temporal. The first three are defined by Ting et. al. and the last is defined by Saj et. al.

Personal Neglect

Personal neglect refers to neglect of one's personal space, which literature exemplifies with "combing, grooming, shaving, recognizing the right half of the body only" and "anosognosia", or when patients are unable to recognize their own disorder [3].

Peripersonal neglect

Peripersonal neglect is neglect of one's peripersonal space (space which can be immediately grasped) and includes "eating food from the right half of the plate and neglecting the food on the left" and "reading the right half of the two pages of an open book" [3]. Figure B.4 is an example of peripersonal neglect.

Extrapersonal neglect

Extrapersonal neglect is neglect of one's extrapersonal space (space beyond one's arm's reach) and includes failure to identify people on the left or collision with objects on the left [3].

Temporal neglect

Unlike the previous three categories, temporal neglect is a non-physical category of neglect. Research [6] describes that those with left spatial neglect are less able to perceive the past, which is the "left [side] [of] a mental timeline." Figure B.5, below, plots the proportion of events patients were able to correctly associate with "past" or "future"; there is a substantial difference for patients with left spatial neglect who are more likely to associate past events as future and vice versa.

Research describes that this existence of temporal neglect implies that time has spatial properties [6]. More importantly, this type of neglect gives interesting insight when it comes to types of neglect faced by those with unilateral spatial neglect: not all types of neglect are physical, meaning even if a design idea could perfectly solve the physical aspects of neglect, it would not be 100% effective at solving all aspects of neglect.

B.3 Reviewing current approaches to left neglect

Current approaches to left neglect are extensive with multiple patented commercial products. Here, two specific therapies are explained in detail.

B.3.1 Specific Solution 1: Prism Adaptation

Prism adaptation treatment is a process in which individuals wear prisms that displace their vision in a specific direction while performing specific direction-related tasks [7]. While research indicates that individuals initially make errors, with repeated trials, the amount of errors decreases [7]. This same research further explains that for those with left neglect, right-shifting prisms shifts movement leftward [7] which directly tackles aforementioned issues regarding personal, peripersonal, and extrapersonal space. However, this solution is unlikely to alleviate temporal neglect due to time not being physical. An ideal solution would provide means to alleviate temporal neglect, though this necessarily complicates the design process by involving both physical and non-physical categories of neglect.

B.3.2 Specific Solution 2: "Visual Attention Therapy" App

Figure B.6 summarizes how the "Visual Attention Therapy" (VAT) App works. When an individual uses this app, they go through a timed trial in which they interact with certain elements spread across an entire tablet screen (A). At the end of the trial, individuals get results indicating where on the screen they were more likely to neglect (B). This information can be used to reduce the number of missed targets by giving individuals instant feedback.

B.3.3 Review of Therapies

Both of these therapies share one flaw: individuals cannot use them at any time, as they have to be in a comfortable, safe environment, meaning this solution is unable to help people when they may need it in public. The prism device is designed to only be worn for 20 or so minutes at a time [7], multiple times per week – literature indicates that at least twice per week prism device usage is needed for rehabilitative effects [7]. The app requires using an electronic device, constraining it to use only where and when an electronic device can be used.

B.4 Conclusion

Left neglect, a subset of unilateral spatial neglect, leads to deficiencies in interaction in affected individuals in multiple categories. These deficiencies decrease individuals' ability to fully interact with their world. Current solutions for left neglect are used in therapy; the two cited are both good examples, but are also restrictive in use cases. Neglect faced by affected individuals reduces quality of life, meaning a general solution for either left or right unilateral spatial neglect would be a critical tool in improving quality of life for affected individuals. However, as indicated in Figure 1, the relative severity of right-side USN makes designing an assistive device for left-side USN both more feasible given time constraints and necessary given its prevalence.

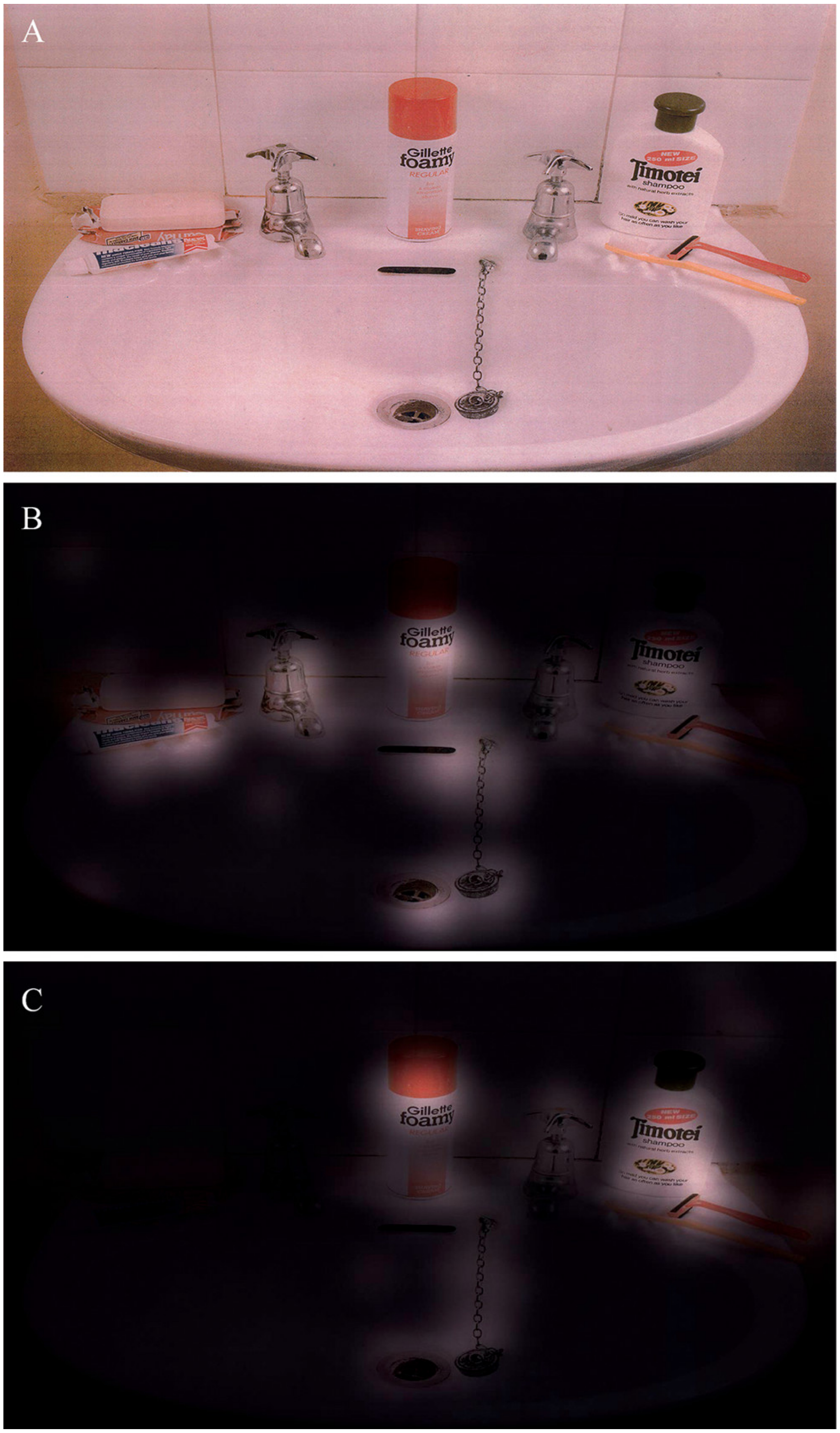

Figure B.2: (A) Behavioral inattention test with a washbasin; (B) healthy participant response; (C) left-neglect response. [4]

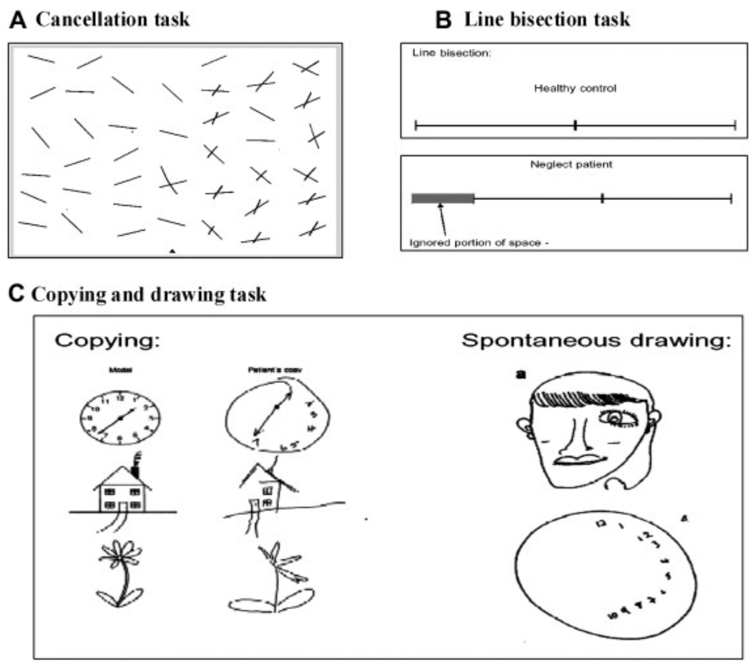

Figure B.3: Diagram depicting patient interaction with their left and right sides. [3]

Figure B.4: Patients with left neglect may only eat the right half of their food [5].

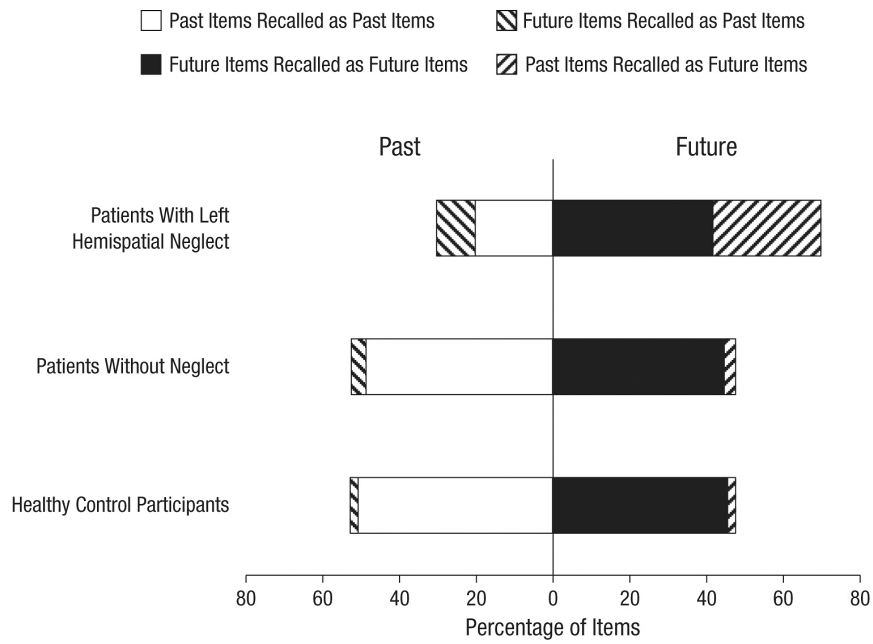

Figure B.5: Temporal neglect of patients with left spatial neglect quantified by percentage of items correctly recalled.

A

B

LEVEL 10: SIMILAR LETTERS				
Target	Time	Found	Location Of Missed Targets	Wrong Target
w	00:47	31/34 91%	Bottom Left: 3 Top Left: 0 Top Right: 0 Bottom Right: 0	0

Figure B.6: (A) Screenshot of VAT App from official website [8]; (B) zoomed in screenshot of test results page which indicates location of missed targets.

Appendix C

Observations Summary

Get the observations sum-
mary

Appendix D

Interviews Summary

Get the interviews sum-
mary

Appendix E

User Testing and Feedback Summary

Get the user feedback summary

Appendix F

Bill of Materials

Write the BOM