Wearable Augmentative and Alternative Communication Device for Speech Impaired Children

Final Report

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ABSTRACT

Constraints in communication can have a detrimental impact on all aspects of life. Up to 14 million people experience communication difficulty at some point in their lives in the UK alone, with more than 10% of children having a long-term communication need [1]. Individuals unable to communicate effectively can benefit from assistive technologies, known as Augmentative and Alternative Communication devices (AAC). This term encompasses all systems, strategies and tools that replace, or support spoken language. According to feedback received from the Pace Centre, a charity that supports children with neurological disabilities, AAC devices currently available on the market can be unhelpful, costly, and frustrating to those with very limited motor control [5].

Recognizing these challenges, the aim of this project was to develop a wearable alternative to the current expensive, wheelchair-mounted AAC models used by many with cerebral palsy. The design is a selection-to-speech device that allows the user to navigate a digital interface and select a sentence or word to output as audio. The selection can be made through either eye tracking or motion sensing, giving the user the flexibility of choosing between both modes depending on their personal ability.

The design consists of three main components: a headset, an arm set, and a hip belt. The headset is comprised of a camera for eye-tracking, a Google Glass to display the digital interface in augmented reality, and a 3D printed frame that mounts these components onto the user's head. The hip belt houses a Raspberry Pi Zero W to process and transfer data from the camera via wires, and a power bank to provide power to the Raspberry Pi and its components. The arm set contains a smartphone, secured by a running armband, and is responsible for motion sensing and audio output.

The current prototype has met the main requirements outlined in the Project Specification Document, as shown in Appendix I. Future work is needed to refine the product and ensure that all components connect as intended. Nevertheless, the primary aim of broadening accessibility and creating a wearable device has been achieved, placing the product ahead of its competitors.

Acknowledgements

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1. Introduction

1.1 Motivation and Project Aims

Approximately 18 million people worldwide live with cerebral palsy (CP) [2], a group of lifelong conditions that permanently affect an individual's posture and muscular coordination. These conditions frequently co-occur with other diagnoses such as epilepsy, attention deficit hyperactivity disorder (ADHD) and auditory and visual impairments [3]. Moreover, they tend to result in communication difficulties, with 50% of individuals with CP having some level of speech impairment [4], 25% of which result in complete inability to communicate verbally [2].

The need for alternative communication methods is evident, yet for severe speech impediments current technologies can be impractical. According to assistive technology professionals, common issues surrounding AAC devices include heavy and bulky mounting systems, limited options for those with severely limited motor control, unreliability, and high purchase and maintenance prices [5].

This project responds to these issues by providing a wearable, easy-to-use communication device for children and adolescents with a CP diagnosis and Gross Motor Function Classification System (GMFCS) score in the 3-5 range. The use of both eye-tracking and motion sensing allows for the accommodation of a wide user-base, as each individual child will have different motor capabilities. The final aim of the design is to enable device users to communicate easily and effectively, ensuring they feel comfortable and confident while having their say.

1.2 Existing Solutions & Background Research

Individuals with speech impairments can choose from a range of existing AAC technologies, some examples of which can be found in *Table 1*. These devices, though suitable for a range of disabilities, often do not meet the unique needs of users with very limited fine motor control (i.e. a potential user with CP and a GMFCS score of 5).

Solution	**Description**	**Constraints/Drawbacks**	**Industry Examples**
Picture Exchange Communication Systems (PECS)	User exchanges images with their communication partner to express a want or need.	Requires fine motor control to handle images. A physical booklet of images must be carried. Limited communication range due to fixed set of words.	 PECS Booklet – Pyramid Education Consultants [6]
Voice Output Communication Aids (VOCAs) & Speech Generation Devices (SGD)	Devices that allow non-verbal users to communicate via speech outputs.	Often not wearable and require mountings or a surface to sit on. Often cater to users with fine motor control in their limbs. Can lack potential for customization and pre-set	 Abilia Lightwriter SL50 [7]

		word lists can restrict range of communication. Typically very expensive to purchase and/or maintain.	 Ablenet BIGmack Communicator [8]  AssistiveWear Proloquo2Go App [9] (and other similar smartphone and tablet applications)
Eye tracking devices	Technology that tracks pupil movements to display where a user is looking or move a cursor within a screen. Can be used together with VOCA/SGD devices such as AAC smartphone and tablet applications.	Often very expensive. Many systems require frequent realignment and recalibration to ensure accurate tracking. Many programs require users to look directly at a sensor or camera for accurate tracking, requiring fine motor control of head and neck muscles. Many require mounting systems.	 Tobii DynaVox Wheelchair Mounting [10]  Tobii Dynavox VOCA device with built in eye-tracking [10]  Tobii DynaVox eye tracking hardware [10]

Table 1: Examples of existing AAC devices

2. Requirements Definition

To tailor the design to the needs of the children at the Pace Centre, a survey was conducted amongst caretakers and Pace Centre staff (Appendix H). This, together with an interview with Mr. Luke Thompson from the Pace Centre [5], informed the main requirements of the design.

Requirements Overview

The device must support and run web-based AAC applications such as, but not limited to, the Pace Centre My Way App.

The headset and arm set should be lightweight and adjustable to fit various head and arm sizes respectively without causing discomfort. It should also be completely wearable eliminating the need for a mains power supply.

The device should be safe to use, protecting users from electrical shock and free of any toxins and allergenic materials.

A further selection of relevant quantitative requirements from the Product Specification Document (PSD) [11] are listed below. The PSD number for each requirement is written in brackets. The PSD itself contains a complete set of requirements and evaluation methods.

Functionality and Performance

- The device must support and run the Pace Centre's My Way communication application. (1)
- The headset and arm set, as well as optional input devices must connect with each other via Bluetooth. (4)

Size and Weight

- Headset should have an adjustable circumference between 41.5cm and 50.4cm (5); weight less than 0.5kg. (6)
- Arm set should have an adjustable circumference between 16.9cm and 27.3cm (7); weight less than 0.2kg. (8)

Interface and Usability

- Font size must be adjustable within the range of 12-20 points. (9)
- The device should be easily operable by CP users in the 3-5 disability spectrum range. (10)

Portability

- Device needs to be able to be worn or attached to the body and does not require external supports. (19)

Safety Standards

- The device must be nontoxic, hypoallergenic, and shatter-proof. (23)

Cost

- The total cost of the AAC device must be lower than current industry pricing for comparable products. Market price should not exceed £2500. (31)

Legal and Regulatory

- The device will undergo a clinical evaluation to evaluate the device's safety. (36)

3. Final Design

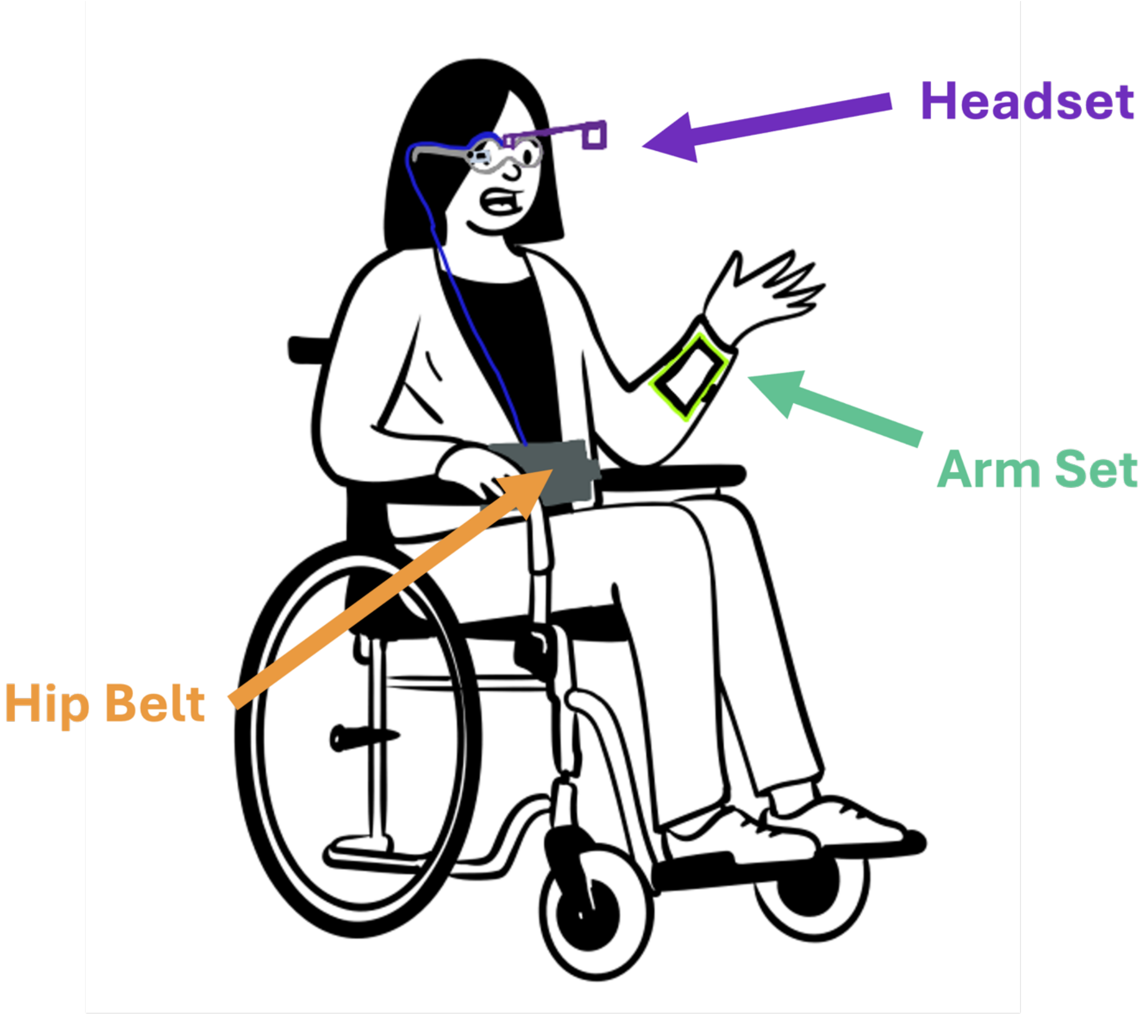
3.1 Design Choices

After a comprehensive morphological analysis, it was decided that the final design would feature a headset-mounted augmented reality (AR) display with an adaptable range of input devices. Additionally, it would aim to achieve general compatibility with existing AAC web-based applications, rather than tailoring specifically to one application.

When designing the inputs, priority was given to developing an eye tracking input for navigation and selection, as those with the most severe motor impairments often only have fine motor control over their ocular muscles. To provide an alternative navigation option for individuals with slightly higher gross motor function, a motion sensing input was designed for the arm. Further consideration was given to incorporating additional input devices in the future to enhance the design adjustability and accessibility for a range of disabilities.

3.2 Design Overview & Physical Assembly

3.2.1 Design Overview



HEAD
- Eye tracking camera
- Visual display

ARM
- Motion Sensing (IMU)
- Speaker
- Optional additional inputs

HIP
- Raspberry Pi (eye tracking processor)
- Power Bank (powers Raspberry Pi and camera)

Figure 1: Overview of the device components

The wearable device consists of 3 independent parts; a headset, arm set, and hip belt, as displayed in *Figure 1*.

The visual display is mounted in the headset for ease of use, while the eye tracking hardware is distributed between the headset and hip belt to reduce the weight on the head, minimize overheating risks, and ensure accurate eye-tracking. The motion sensing input is mounted to the arm set, which also houses the speaker and serves as a potential mounting point for future input devices.

3.2.2 The AR Display Hardware

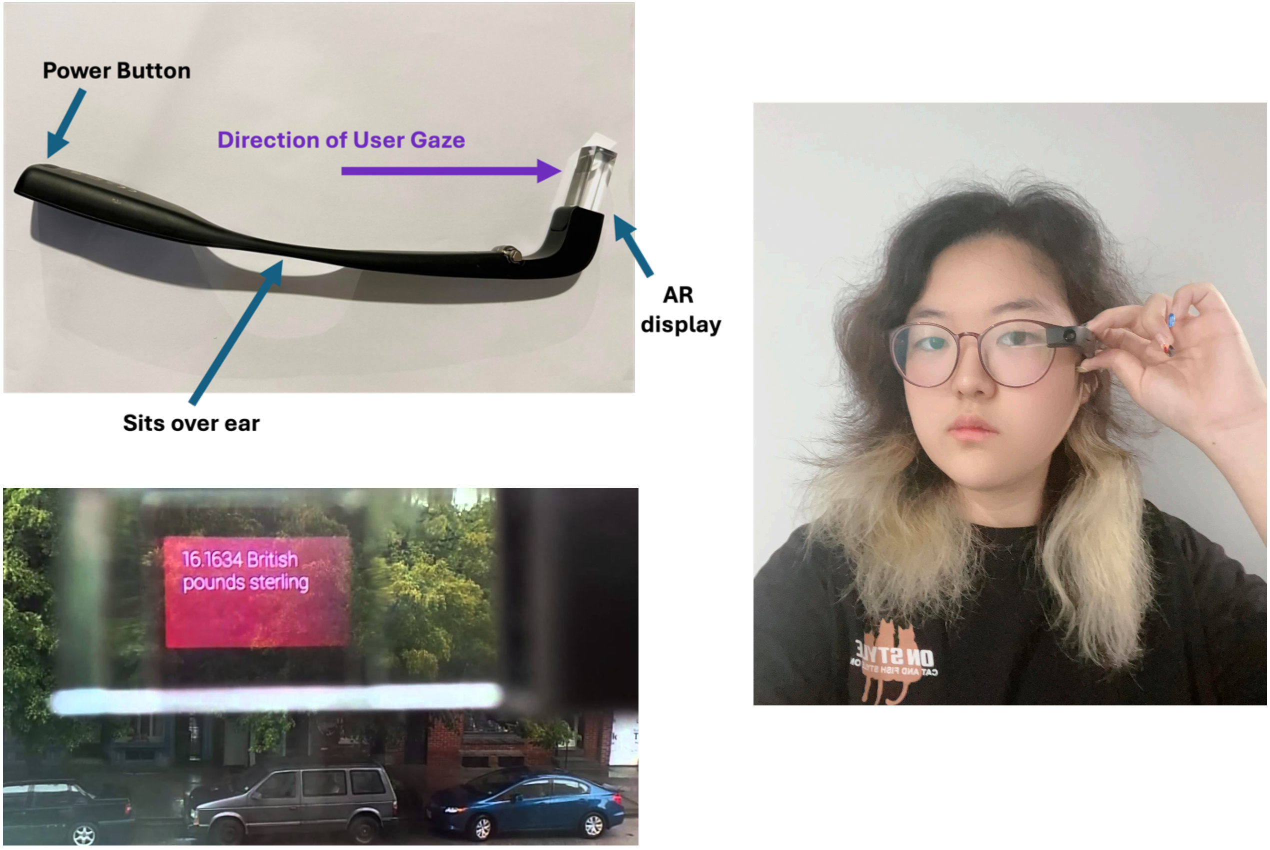


Figure 2: Google Glass (top left); Google Glass internal display (bottom left)[12]; Google Glass user demo (right)

To account for additional sensory sensitivities often experienced by individuals with CP, the device was designed to be minimalistic and customizable. To achieve this, it is important that the AR experience does not include unnecessarily distracting displays or hinder the user's line of sight. Additionally, careful consideration was given to user privacy, particularly ensuring that the contents of the AAC display were concealed from those around them. The Google Glass Enterprise Edition 2 was selected due to its light weight and the fact that its display takes up 5% of the visual field and is located to the side of the user's direct line of vision [13]. Additionally, the Google Glass display is only visible to the user, eliminating privacy concerns. The history of privacy concerns regarding the Google Glass's outward facing camera were directly addressed by both disabling the camera and covering the lens.

The Google Glass is shown in *Figure 2*, with an example of its built-in AR display.

3.2.3 The Headset Mounting

The headset mounting serves 2 main purposes; securely attaching the Google Glass to hold the AR display in place and providing a sturdy attachment point for the camera. Two of the largest issues with current eye tracking models are the need for constant recalibration of the software due to changes in head position, and the fine muscle control required to keep the head aligned with the sensor [5]. To address this, the camera is mounted to the headset to ensure a fixed location relative to the user's eyes.

To minimize discomfort, the headset mounting was chosen to mimic standard glasses frames, resting on the bridge of the nose and over the ears. The presence of over-the-ear supports on both sides of the head ensures the Google Glass will sit securely in place. Loops for the attachment of optional straps provides additional user choice. These straps can be adjusted using Velcro to fit to the dimensions of the specific user. The frames of the headset are left empty to allow users to insert personal prescription lenses if needed.

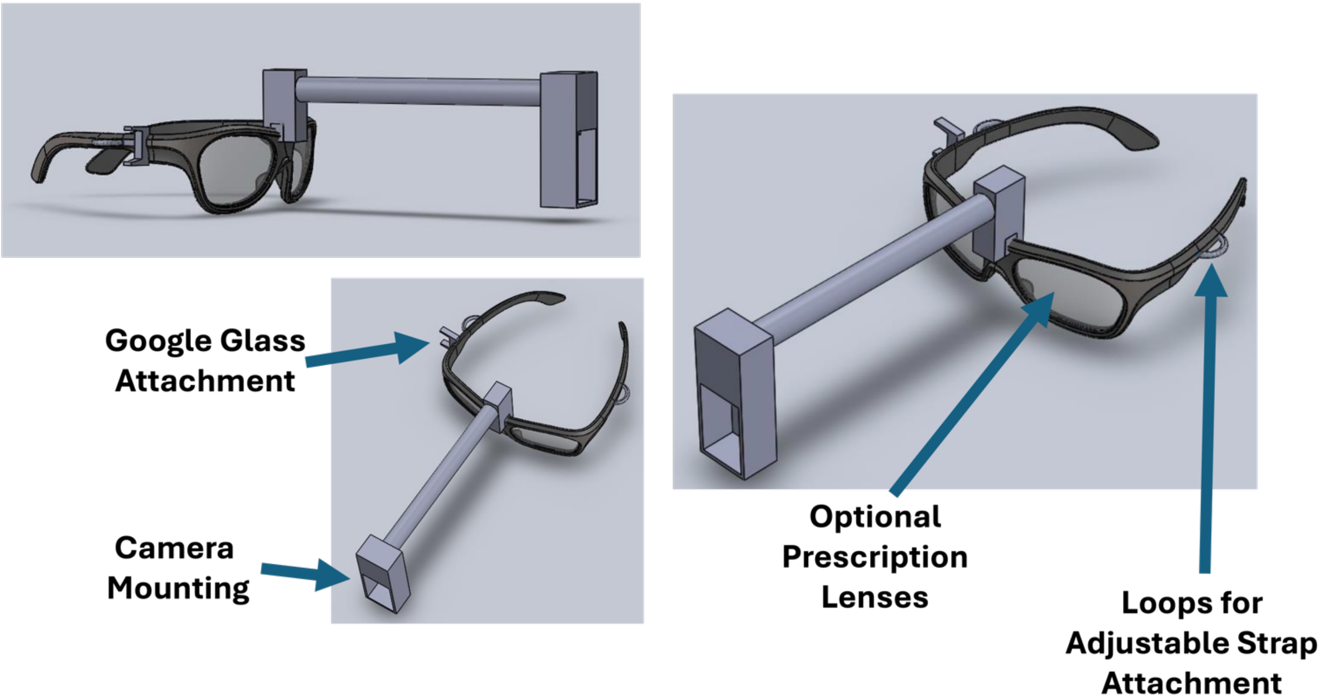


Figure 3: Headset with Google Glass attachment points.

The Google Glass attaches securely to the headset via a side mounted attachment clip, as labelled in *Figure 3,* which has an allowed tolerance of 0.3mm.

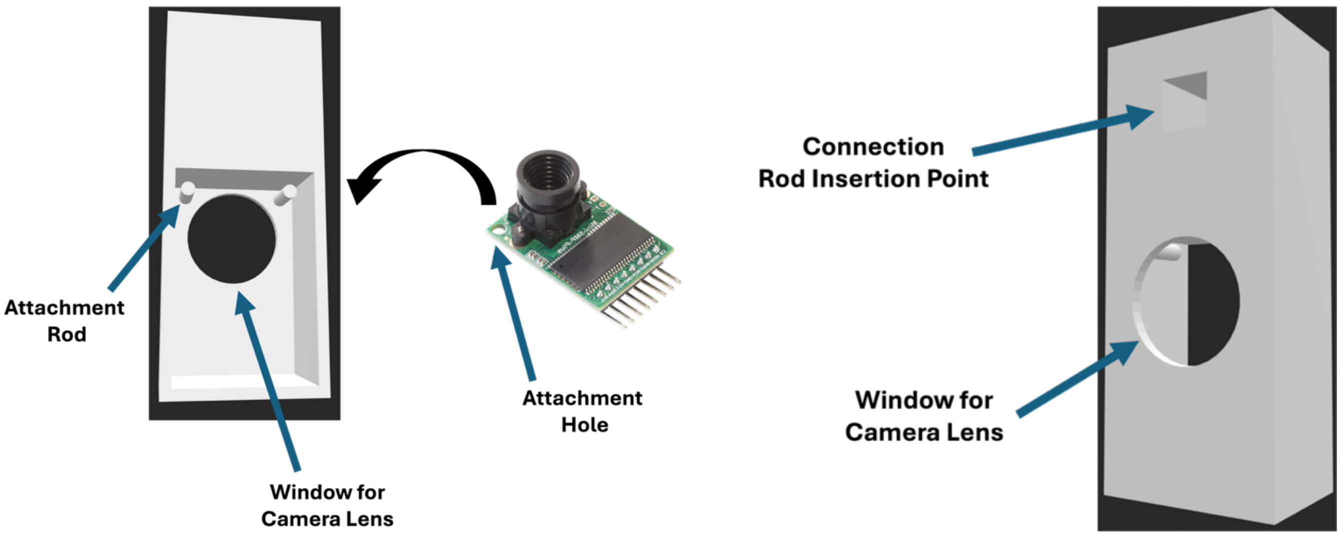


Figure 4: Camera casing

The camera module selected for use in the headset is the Mini 2MP SPI Camera Module (ArduCam), chosen for its compactness (24.40 mm x 34.10 mm), high resolution (2 Megapixels), low power consumption, and price. To secure the camera in place, a casing was created as shown in *Figure 4*.

Within the casing, the camera is held in place by the presence of two extruded rods that have a transition fit with the camera attachment holes.

The camera casing is connected to the main headset via a 13cm rod that sits on the rim of the glasses. 13cm proved an optimal distance for eye tracking activity following prototype testing. The computer-aided design (CAD) of the full headset is shown in *Figure 3*.

Nylon-12 (PA 2200) was chosen to manufacture the headset components due to its considerable tensile strength, stiffness, chemical resistance, and biocompatibility [14]. It is also compatible with Selective Laser Sintering (SLS), which was chosen for initial production due to its ability to produce highly intricate geometries, its smoother and higher quality finish compared to fused deposition printing, and its ability to print customizable models for each user as opposed to methods like injection molding.

3.2.4 The Arm Set & Hip Belt Mounting

Figure 5: Armband for the smartphone (top); Hip belt and arm set (bottom)

The arm set consists of a mounting for additional input mechanisms, namely motion sensing, and a speaker for audio output. These components are currently contained within a standard Android smartphone, which is encased in the armband shown in *Figure 5*. The armband is made from Thermoplastic Polyurethane (TPU) which has high wear resistance, tear strength, elasticity, and resistance to degradation by oils, greases and sweat naturally secreted by skin. TPU is also a well renowned shock absorbent, protecting the phone from impact damage [15]. The armband is compatible with smartphones of length 4-6.8 inches; this range encompasses almost all the mobile devices available in the current market. The hip belt consists of a cloth hip bag (*Figure 5*) containing an insulated case with the Raspberry Pi Zero W and its electrical wiring to the ArduCam and power bank.

3.2.5 Inputs & Information Flow

To accommodate users who only have fine motor control over their eyes, eye-tracking was developed as the primary input method. By moving their eyes and hovering over a button within the display, users can move a cursor and make selections within their AAC web application. For users with more fine motor control, an inertial measurement unit (IMU) within the smartphone on their sleeve records arm movements to control the cursor and select output. The device was also designed to implement a button and other assistive inputs (joysticks, touchpads, etc.) to allow for more customizable forms of control and selection. The flow of information from the inputs to the display can be seen in *Figure 6*.

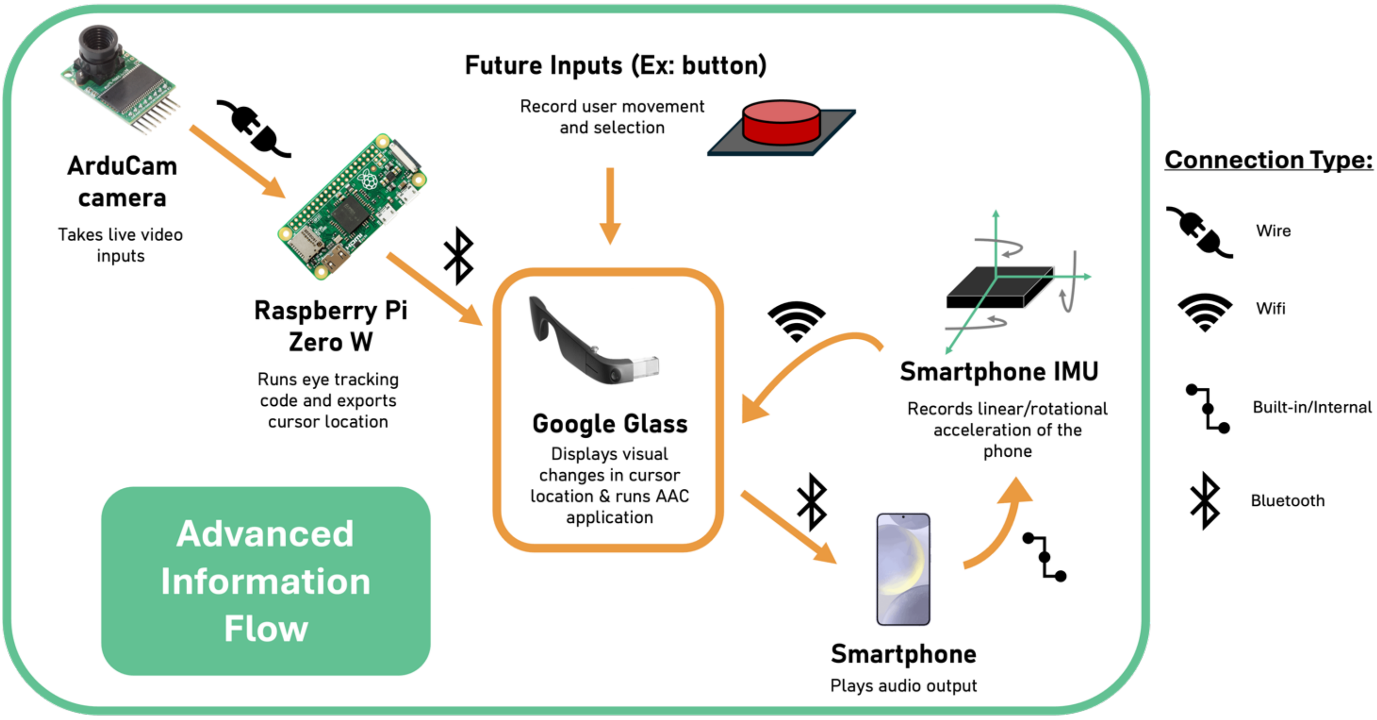


Figure 6: Schematic of information flow

3.3 Visual Display (VD)

To display a web-based AAC application in the AR display, an Android application was written that could be packaged and deployed in the headset. Once opened in the Google Glass, the application uses the Java WebView class to open a user interface (UI) and display a live webpage which the user can navigate.

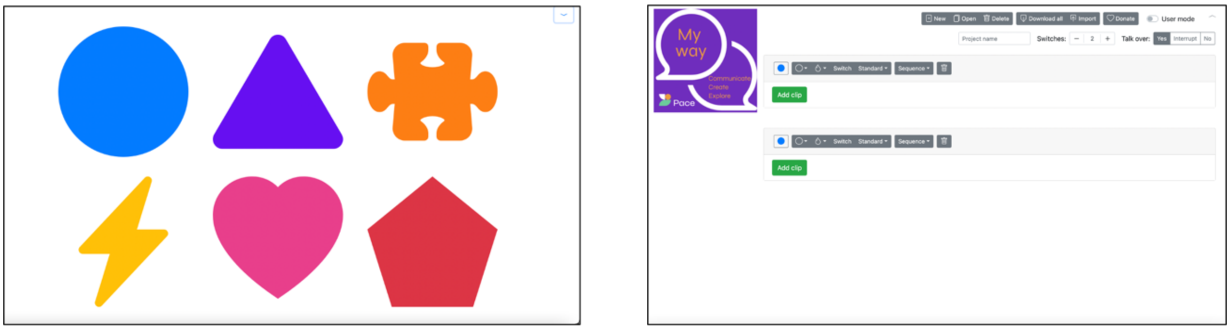


Figure 7: Interface of My Way app

To test the application, the Pace Centre My Way web application was employed, with an interface as shown in *Figure 7*. The My Way application was chosen for testing due to its preferential use by target users in the Pace Centre school. By embedding a link to another AAC web-based application into the Android application, the user could also run any other AAC web application of choice.

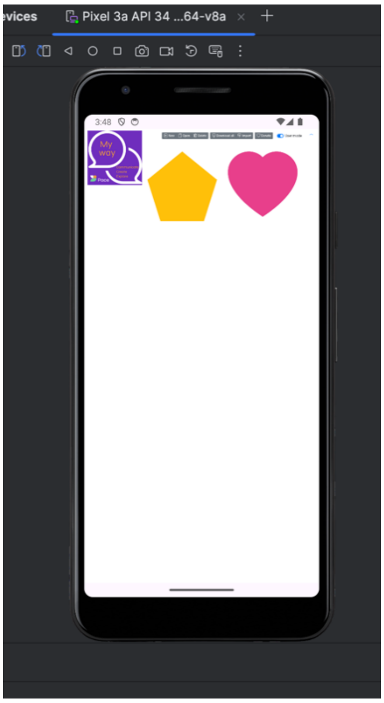


Figure 8: Android Studio output

Android Studio was used to write and test the application, and a sample output of the display can be seen running on a simulated smartphone within Android Studio in *Figure 8*. The application was written primarily in Java, with the use of XML to adjust the UI, and Gradle build automation tool to package and deploy the Android Application Package (APK) to the Google Glass.

3.4 Input Mechanisms

3.4.1 Eye tracking

To track eye-movements, an ArduCam camera is mounted to the headset as seen in *Figure 4*.

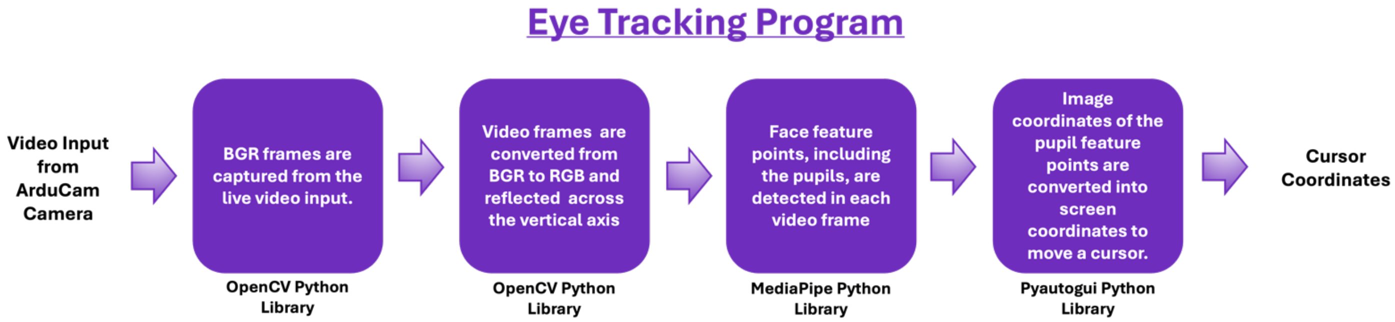


Figure 9: Schematic of eye tracking program

This camera is wired to a Raspberry Pi Zero W which processes the input using the eye tracking program shown in *Figure 9*. This program is written in Python, runs on the Raspberry Pi, and translates the camera stream into live cursor locations. The information regarding cursor location is then sent via Bluetooth to the application displaying the AAC in the VD. This results in the cursor moving across the VD by following the user's pupil movements as detected and processed within the program.

3.4.2 Motion Sensing

For users with finer motor control, motion sensing is an optional additional input that can help relieve the possible fatigue associated with long duration eye-tracking. To fulfil the goal of controlling a cursor with external limb motion, linear acceleration of the phone within the arm set sleeve is converted to displacement of the cursor.

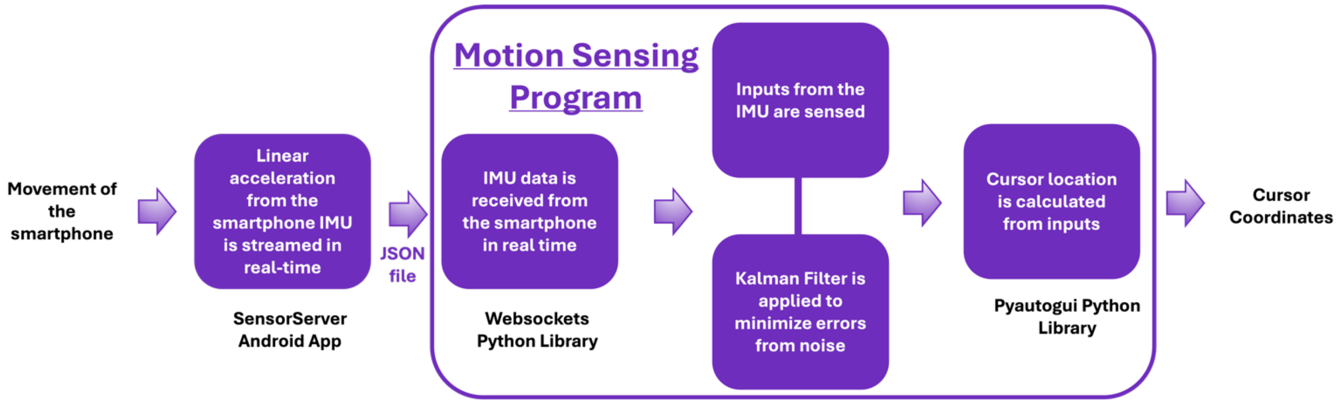
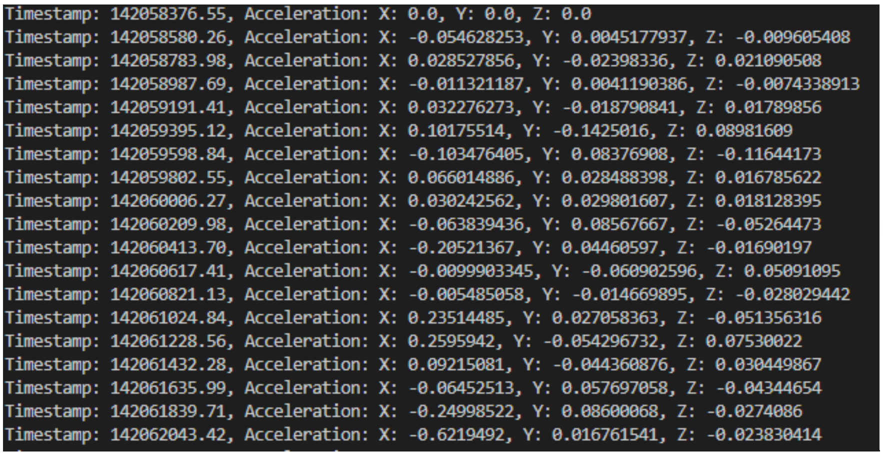


Figure 10: Schematic of information flow for motion sensing

The Android application SensorServer is run within the smartphone in the arm set to collect linear acceleration data from the built-in IMU as shown in *Figure 11* and *Figure 12*. This information is sent as a JSON file using IP addresses and local Wi-Fi and used as the input to a motion sensing program written in Python (*Figure 10*). This program processes the IMU acceleration data and transforms it into cursor displacements and live location within a VD. To recursively remove the noise presented by the input, a Kalman filter is implemented.



```
Timestamp: 142058376.55, Acceleration: X: 0.0, Y: 0.0, Z: 0.0
Timestamp: 142058580.26, Acceleration: X: -0.054628253, Y: 0.0045177937, Z: -0.009605408
Timestamp: 142058783.98, Acceleration: X: 0.028527856, Y: -0.02398336, Z: 0.021090508
Timestamp: 142058987.69, Acceleration: X: -0.011321187, Y: 0.0041190386, Z: -0.0074338913
Timestamp: 142059191.41, Acceleration: X: 0.032276273, Y: -0.018790841, Z: 0.01789856
Timestamp: 142059395.12, Acceleration: X: 0.10175514, Y: -0.1425016, Z: 0.08981609
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Timestamp: 142060006.27, Acceleration: X: 0.030242562, Y: 0.029801607, Z: 0.018128395
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```

Figure 11: Live cursor location

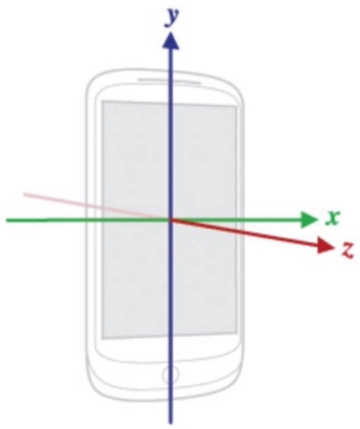

Figure 12: Coordinate system used [16]

To incorporate this program into the application running the AAC web page and thus the final AAC device, this program will have to be called from the Java program running in the Android application using a Java bindings library such as Jython. This will allow the app to transform inputs from the JSON file into cursor movements that the user can see and use for navigation and selection.

3.4.3 Selection & Outputs

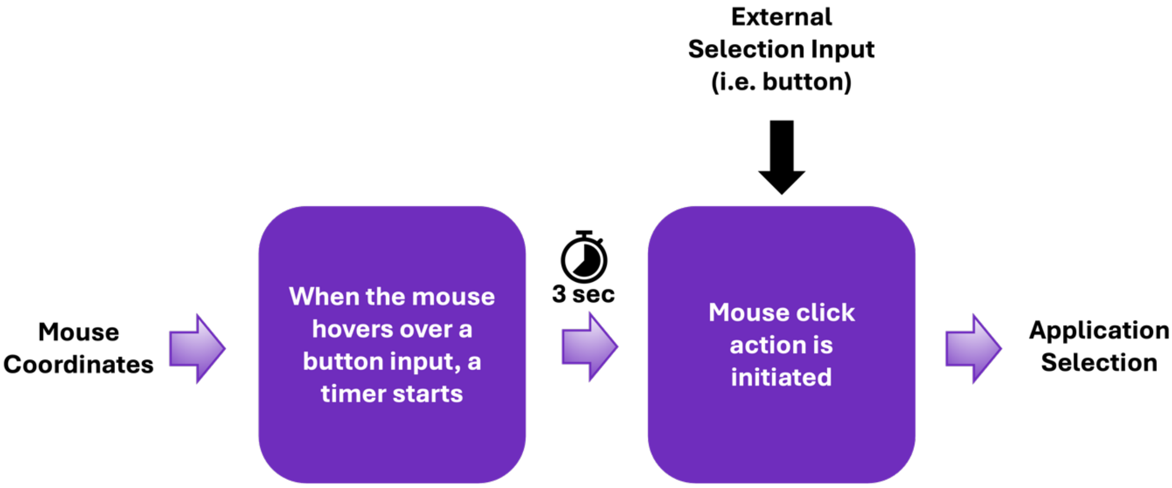

Figure 13: Schematics of selection process

When the user utilizes one of the optional input methods, they will control a cursor location within the VD. To then select an output within the application, they have 2 options: time-based selection, and external input selection. If time-based selection is used, the user hovers over a button in the application for 3 seconds to initiate a cursor "click" selection (*Figure 13*). This type of selection allows users who only have control over their eye movements to both navigate and select using their eyes, without the need for additional inputs.

Eye fatigue is common when using eye tracking technology [5] and can be addressed by introducing alternative selection methods for users who are not restricted to eye-based control. Although not yet implemented, in the future the design will support alternative inputs, including a push button, allowing users with greater motor control to make a manual selection after moving the cursor to the desired location.

3.4.4 Additional Physical Inputs

Customizability is fundamental to ensuring maximum comfort and performance for users, thus the design was implemented to allow for multiple input options. The design configuration supports the future incorporation of specialized inputs such as joysticks, push buttons, and touchpads. These inputs would be implemented via a Bluetooth connection to the Android application running in the Google Glass headset, allowing users to make selections and navigate the visual display with greater choice.

4. Discussion

4.1 Design evaluation

4.1.1 Testing Methods

Eye tracking

During the programming process and after the code was completed, small user trials were conducted to assess the effectiveness of the program's core features. The viability of the program was tested by instructing users to operate it under varying environmental conditions to assess:

- Sensitivity to different ranges of motion
- Accuracy of the tracking mechanism
- Lighting requirements for accurate function
- Effectiveness of the program with the use of prescription lenses
- Latency

Motion Sensing

The motion sensing program was tested similarly to the eye-tracking program, where test users were asked to complete tasks while their performance and feedback was recorded. The program success was assessed using the following categories:

- Input noise removal
- Latency
- Required range of motion
- Mobile accuracy
- Stationary accuracy
- Comfort

Other Testing

Additional testing has been planned and undertaken to evaluate the fully integrated design. This testing assesses:

- Mechanical sturdiness
- Device connections and integration
- Battery life
- GDPR compliance
- Medical safety

A detailed description of the assessment methods used for all metrics can be found in Appendix I.

4.1.2 Results

Fulfilment of requirements

Eye tracking code

The eye tracking code developed for this product successfully allows navigation of a visual display. The code relies on a combination of eye and head movement to move the cursor, which requires future improvement as the camera will ultimately be in a fixed position relative to head. Further improvement of sensitivity and accuracy of the program are needed, and an individual calibration mechanism to configure the program for each individual user will need to be developed.

IMU code

The code is currently reliable in its ability to detect a stationary input and filter out input noise. Further testing is needed to fully assess the functionality of the program when there is a linear acceleration of the phone. IP address and connectivity need to be tested for multiple inputs and overall process speed will need to be improved.

Google Glass and Android application

The Android application that was created to display the AAC interface was successful but requires the use of a wire connection for successful deployment. The Google Glass effectively demonstrated the hardware necessary for running a communication platform in AR. Google Glass is not a viable option for mass production (Appendix C) and for effective scaling of this design to occur, an alternative headset would have to be constructed to the specifications.

Mechanical

The headset design relied heavily on the functionality of the Google Glass, which arrived in the United Kingdom in late April. This delay afforded the team minimal time to print and test the design. Despite this, the glasses were successful, and the camera was placed in a way that did not completely obstruct vision and facilitated eye tracking.

The clip to secure the Google Glass in place was not effective due to incorrect sizing and will require future adjustment. The clip will also need to be adjusted to hold the Google Glass at an appropriate distance and angle to maximize each user’s viewing experience. Future designs should have the strap holders vertical, built into the frames themselves.

No testing has been conducted yet to determine how the weight of the glasses over an extended period could affect the user.

Selection code

The selection code functions effectively, resulting in a selection after three seconds of hovering over a button input. To make the device more specific for each user’s need, a physical button could be used instead or alongside this feature. Alternatively, the user could be given the option to customize the hover duration before selection.

Cost

The cost of the prototype is well below the industry standard of £2500. The most expensive aspect of the product was the SLS printing needed for the glasses, which can be circumvented in mass production where other methods including injection molding could be used. The design is also modular and the user can decide if they want to use both the eye tracking and motion sensing, or just one, which reduces the price.

Wearability

The device is completely wearable, as set out in the requirements.

Useability

Each iteration of the device was designed with a strong focus on user experience. The device offers multiple usage options tailored to the specific needs of each user, depending on the severity of disability. This is in line with the initial requirements for the device.

4.1.3 Discussion

Design Evaluation Matrix

Design Requirement	Design Outcome	Success	PSD Line Reference [11]
Device supports and runs My Way Pace Centre App.	The My Way App, as well as any other website-based AAC can be opened, run and displayed within the AR display.	Yes	1
Headset and arm set must connect with each other via Bluetooth	Bluetooth connection has not yet been implemented to fully connect headset, arm set, and hip belt	No	4
Headset and arm set must have adjustable circumferences to fit different users	The arm set can be adjusted within the full range of required circumferences. The headset circumference is fully adjustable in SolidWorks, but not after production	Partial	5,7
Font sizes must be adjustable between 12-20 points	Font size is fully adjustable when the AAC application is first deployed but cannot be adjusted by the user afterwards.	Partial	9
Accessible to users in the 3-5 range of the GMFCS	Design was constructed with the intention to be implemented for users in the 3-5 range of the GMFCS scale, but no surveying or testing with users of this type has been conducted.	Partial	10
The device must be fully wearable and not require any external supports.	All portions of the design can be fully worn on the body.	Yes	19
Safe materials selection in all portions of the design	All materials in contact with the body are biocompatible and hypo allergenic. Consideration was made for fabric breathability and thermal/electric insulation.	Yes	23
Device must be affordable and not exceed the cost of comparable technologies on the market (£2500)	The final design cost without accounting for transportation of parts and additional manufacturing expenditure is £597.03.	Yes	31
Clinical evaluation of the technology will be carried out to assess its safety for children with CP and other sensory sensitivities.	No clinical evaluation of the design has been undertaken yet.	No	36

Table 2: Design evaluation matrix

Evaluation conclusion

Overall, the design follows the requirements the team created at the beginning of the project, with a few exceptions. Due to the time constraints caused by the long shipment of the Google Glass from the United States and major design changes that occurred throughout the iterative process, the prototype was unable to be fully completed. The team was unable to integrate the sections together fully and have the whole prototype connect via Bluetooth.

Ideally, the team would have sent the prototype to the Pace Centre community to acquire feedback from users, guardians, caretakers, and teachers. This would have been the final stage of testing, after making sure the device was safe both physically and in terms of data protection.

4.1.4 Future Improvements

4.1.4.1 Immediate future improvement

The group had insufficient time to integrate all sections. Therefore, the design needs to be completed, implemented, and tested in its current state prior to additional longer-term improvements. This mainly constitutes ensuring seamless integration of all sections, enabling communication via Bluetooth, and completing electrical circuit connections.

4.1.4.2 Long term improvements

More compact design
The smartphone in the arm set will be replaced by a small microprocessor and IMU sensors, reducing the weight and allowing users to use motion sensing for longer periods of time without muscle fatigue.

Improved settings navigation
To improve user experience, a “settings” button will be added to the digital interface, allowing users to change between eye-tracking and motion sensing. There will also be an external switch that allows for selection to replace the time-based selection if the user prefers.

Infrared eye tracking
Infrared technology enhances eye tracking accuracy by allowing more reliable data collection and analysis for individuals wearing glasses/contact lenses.

Speech generation
A predictive program using symbols, or a QWERTY keyboard will be incorporated for users with speech impairments, enhancing conversational efficiency, lowering eye tracking or motion sensing fatigue, and increasing conversation speed.

Compatibility with more apps
Currently, only the Pace Centre My Way app has been tested, and the interface has only been designed for website-based AAC applications. Future iterations will include compatibility with non-web-based AAC applications, enabling users to continue with their accustomed software and reducing additional financial burden.

Diversified inputs
Users within the GMFCS range of 3-5 have significantly reduced muscle control. Therefore, the eye tracking and motion sensing inputs may be insufficient to meet every individual’s needs. A wider range of input devices including, but not limited to, pedals, levers, and buttons on the fingers or palm, will be supported to customize the device to the unique requirements of each person.

4.2 Group dynamics

4.2.1 Team organization

The team was divided into 3 sub-groups: mechanical, electrical, and computational. Group members were assigned according to their interests and skillset. Sub-group leaders were chosen to delegate internal tasks equally amongst the sub-groups. As the project progressed and changed, groups were given the opportunity to reallocate assignments based on upcoming deadlines.

The group met regularly online and in person, typically twice every week, and sub-groups met independently according to their own schedules and needs. Group members were urged to join in person as discussing ideas face-to-face rendered the meetings more productive. During every meeting, notes were taken for any absent group members, as well as for future reference.

4.2.2 Team achievements

Consistency and attendance

The group met on a regular basis and most members were present for both the internal meetings as well as the supervisor sessions. Ahead of every meeting, an agenda containing all pressing discussion points was outlined to ensure the meeting ran smoothly and efficiently.

Online communication

The group mainly communicated on WhatsApp and files were exchanged via Teams. Using WhatsApp allowed members to receive quick feedback from others as everyone was responsive.

Timeline

Each member's schedule and deadlines were considered when distributing work. This ensured that no member was falling behind in other subjects and no unnecessary stress was caused by the project during busy periods i.e. exams.

Flexibility

Working in a group of ten people made it challenging to schedule meetings that fit everyone's timetable. Hence, those unable to attend were always given the option to join via video call.

Task distribution

The group managed to distribute tasks equally and fairly, making sure to allocate tasks aligning with everyone's interests.

4.2.3 Future improvements

Information flow

Due to the constant adjustments and complexity of the design, there was a lot of uncertainty about the details of the final design. Although meeting notes were taken, the design would have been made clearer if the group had kept a file with an updated summary of the most recent project idea, incorporating sketches and any other relevant information.

Time planning

Finalizing the design and building the prototype required more time than anticipated. In hindsight, the group invested too much time and effort into the initial research and brainstorming of the product and would have benefited from better time management and better use of the Gantt chart (Appendix B).

Punctuality

Towards the end of the project, most meetings would start with a 20-minute delay due to group members not arriving punctually. Although there was a system in place where the last person to arrive had to take meeting notes, this was not very effective. To mitigate this, a heavier penalty could have been introduced for people that were frequently late.

Communication of absence

Often, there were uncertainties regarding whether certain people were going to attend the meeting or not and absences should have been communicated better. A spreadsheet detailing anticipated attendance could have been used to address the problem.

4.3 Conclusion

The main objective of the project was to create an AAC device that was fully wearable, personalisable and affordable. To determine whether the prototype achieved this, feedback from users and their caretakers needs to be obtained. Before this is possible, connection between all parts of the device must be achieved. Unfortunately, the team has not yet accomplished this. However, the technology developed has met the objectives and with further improvement could meet the needs outlined by the Pace Centre.

In the design process, each member of the group developed new skills, learned from each other and experienced the challenges of design development. Although the team worked effectively throughout the year, difficulties were faced when members failed to communicate their needs. Learning to communicate as a teammate is a transferable skill each group member will use in all future collaborations.

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Appendix A – Project Management

Sofia Hospodar – Project Manager

- Organization of weekly meetings
- Google Glass application development and integration
- Headset design formulation
- 3D printing
- PSD editor

Pavithra Hari Krishnan – Procurement Manager

- Ordering components and managing the team's budget
- Mechanical component research and design
- CAD design
-

Weronika Wakula – Manufacturing Manager, Electrical Subgroup Leader

- Electrical component research and design
- AR research
- Presentation editor
- PSD editor
- Poster editor

Kilian Borowsky – Computational Subgroup Leader

- Time-based selection coding
- AR research
- PSD editor

Rhianne Henderson – Mechanical Subgroup Leader

- Mechanical component research and design
- Meeting minutes
- Poster editor

Nora Fang

- Electrical component research and design
- Mechanical component research and design
- Cursor navigation coding
- IMU coding

Om Mahajan

- Cursor navigation coding
- IMU coding
- Poster editor

Ruolin Zhao

- Electrical component research and design
- Mechanical component research and design
- Eye tracking coding

Victoria Walker

- Electrical component research and design
- Mechanical component research and design
- Poster editor

Weizhen Pan

- Electrical component research and design
- Mechanical component research and design
- CAD design

Appendix B – Gantt Chart

Current Week: 37

Task	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Research	4	2	4	2	100%
Communicate with Pace Center/Caregivers	4	1	4	2	100%
Programming CW1	5	1	5	1	100%
Project Specification Doc (First Draft)	5	4	5	4	100%
Full Ideas Brainstorm	9	3	9	9	100%
Programming CW2	11	1	11	1	100%
Check Back with Pace Center	12	1	12	1	100%
December Holiday	12	3	12	3	100%
January Exams	15	1	15	1	100%
Group Presentation Video	16	5	17	4	100%
Computational Design and Analysis	15	9	21	8	80%
Project Specification Doc (Final Draft)	20	4	21	3	100%
Complete Testing of Prototypes	22	4	34	3	70%
Order Materials for Prototype	23	1	23	1	100%
Complete and Print Posters	24	3	33	4	100%
Build Final Prototype	25	12	28	9	90%
Write Final Report	25	13	34	3	100%
Spring Holiday	26	5	26	5	100%
Summer Exams	30	5	30	5	100%

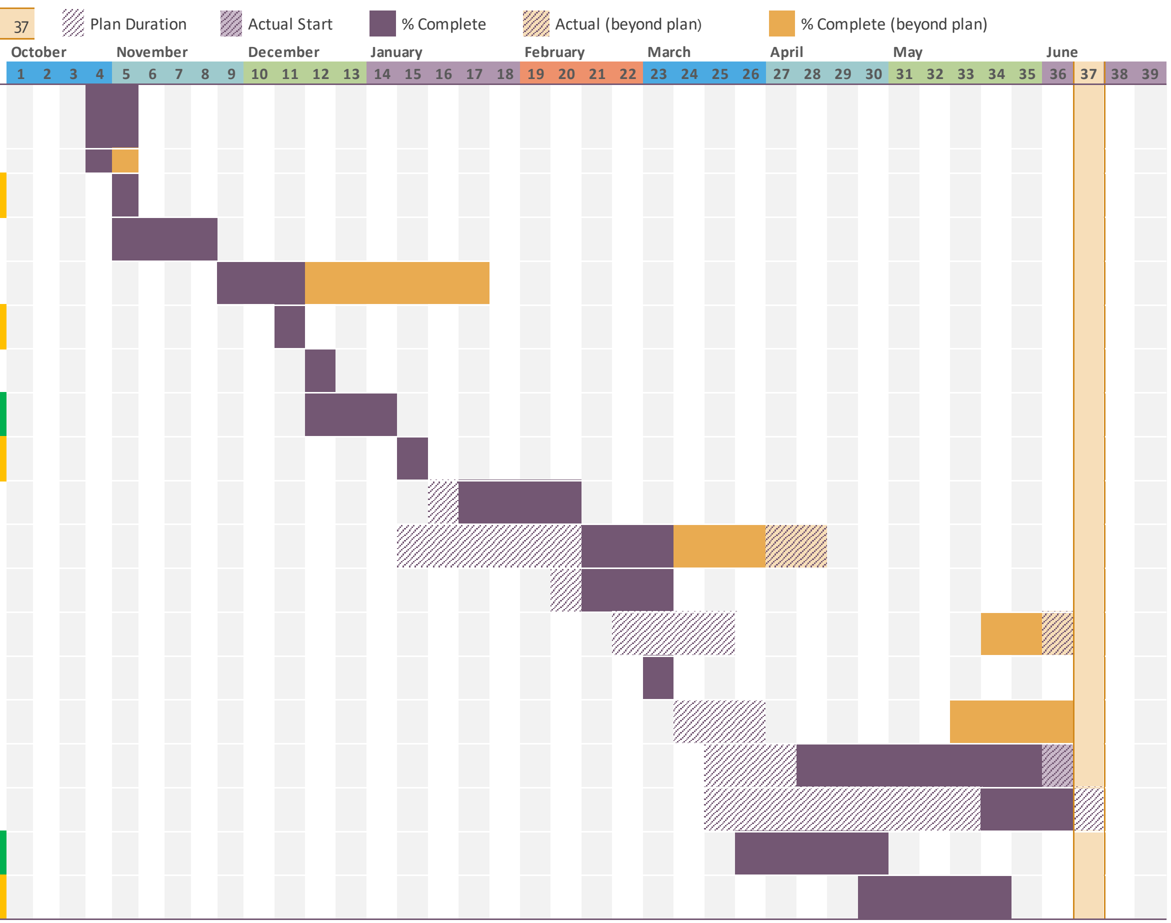

Figure14: The Gantt chart

Appendix C – Scalability Analysis

Short-term Design Scalability Assessment

Currently, the design has the potential to be scaled to meet the demand of the target audience, Pace Centre students. Google Glass models are available to be purchased on e-commerce pages such as eBay in limited quantities that are sufficient for small-scale production. When creating headset mounting components for each user, computer-aided designs can be adjusted using parameterizations within the software to fit securely to each user’s facial dimensions. 3D printing allows for easy customizability to each user based on these adjustments, and all other components can be purchased in sufficient quantity.

Long-term Design Scalability Assessment

Were the device to be put to a larger consumer market, long-term scalability would require slight modifications to the component list and manufacturing methods, namely an updated AR display and the use of injection molded headset components.

The Google Glass Enterprise Edition 2, which is implemented for its AR display in the current design, was discontinued in 2023 and is consequently not a viable option for mass production. In its place, an alternative optical display with similar AR properties would need to be constructed with the assistance of optical engineering professionals.

While 3D printing is a beneficial option for small-scale production, it is too costly and time-intensive for mass production. In future, the transition to injection molding a range of headset sizes would allow the design to be implemented on a larger scale in a cheaper and more efficient manner without losing the capacity to cater to different age groups and head sizes.

All other components in both the current design and the proposed future iterations could be purchased in sufficient quantities to support long-term scalability.

Future Steps & Analyses

Prior to scaling up design production or taking the product to market, it is essential that a full techno-economic analysis (TEA) and life cycle analysis (LCA) are carried out.

A TEA is a critical part of assessing the commercial viability of the design and needs to consider not only the design itself but also the inputs and raw materials, manufacturing facilities and expenditure, and any downstream processing or packaging that needs to take place to produce the final product. Additionally, a more thorough analysis of the market would need to be done to consider whether AAC users would be interested in purchasing the device as well as if the device has potential to sell to a general consumer base.

A LCA is another necessary part of assessing the scalability of the design, this time considering the environmental impacts of scaling up the design. The LCA needs to consider the raw materials used, production processes, transportation, usage, and disposal of the device at the end-of-life. These considerations are critical to an informed decision about the scalability impacts of the design.

Appendix D – Risk Management

Examples of possible hazards are listed below (based on ISO14971):

Examples of energy hazards	**Examples of biological and chemical hazards**	**Examples of operational hazards**	**Examples of information hazards**
Electromagnetic energy Line voltage Leakage current enclosure leakage current earth leakage current patient leakage current **Electric fields** Magnetic fields **Radiation energy** Ionizing radiation Non-ionizing radiation **Thermal energy** **High temperature** Low temperature **Mechanical energy** Gravity falling suspended masses Vibration Stored energy Moving parts Torsion, shear and tensile Force Moving and positioning of pilot **Acoustic energy** ultrasonic energy infrasound energy	**Biological** Bacteria Viruses Other agents (e.g. prions) Re- or cross-infection **Chemical** Exposure of airway, tissues, environment or property, e.g. to foreign materials: acids or alkalis residues contaminates additives or processing aids cleaning, disinfecting or testing agents degradation products medical gasses anaesthetic products **Biocompatibility** Toxicity of chemical constituents, e.g.: allergenicity/irritancy pyrogenicity	**Function** Incorrect or inappropriate output or functionality Incorrect measurement Erroneous data transfer Loss or deterioration of function **Use error** Attentional failure Memory failure Rule-based failure Knowledge-based failure Routine violation	**Labelling** Incomplete instructions for use Inadequate description of performance characteristics Inadequate specification of intended use Inadequate disclosure of limitations **Operating instructions** Inadequate specification of accessories to be used with the device Inadequate specification of pre-use checks Over-complicated operating Instructions **Warnings** of side effects of hazards likely with re-useof single-use medical devices **Specification of service and maintenance**

sound			

Table 3: Examples of possible hazards

Critical Risk Priority Number

During the risk analysis, each risk or failure is analyzed and rated with respect to its severity (S), probability of occurrence (O), and detection rate (D). The rating for each of the three aspects ranges from 1 (low security risk/failure, low probability of occurrence, high detection probability) to 10 (severe injuries or death, high probability of occurrence, no/low probability for detection). The product out of these three ratings is called Risk Priority Number (RPN). In case the RPN is greater than a critical threshold, prevention measures are required to reach a final RPN below or equal to the critical threshold by means of reasonable and justifiable security measures.

For this section, a **critical RPN threshold of 70** was set.

In case the risk is greater than the critical threshold the risk **must clearly be mentioned** in the “declaration of agreement” signed by the pilot and involved staff.

Factors of the Risk Priority Number (RPN)

Find below a recommendation on how to rate occurrence, severity, and detection. The “Risk Priority Number before” is a mathematical product of the numerical Severity- (S), Occurrence- (O), and Detection-Ratings (D) obtained before applying any preventing measures to reduce the likelihood for dangerous incidents, thus: **RPN before = (S1) x (O1) x (D1)**. This “RPN before” should be set to prioritize items that require additional quality planning or action.

The “RPN after” is a mathematical product of the numerical Severity- (S), Occurrence- (O), and Detection-Ratings (D) obtained after applying the preventing measures to reduce the likelihood for dangerous incidents, i.e. **RPN after = (S2) x (O2) x (D2)**. The “RPN after” must be equal or below the predefined threshold to guarantee safe use of the part/element/device.

Preventing measures are mechanisms that prevent the cause of the failure mode from occurring or that detect the failure and stop the application before an incident can happen. It could also reduce the severity by e.g. designing softer and rounder edges. Preventing measures could include specific inspection, testing or quality assurance procedures; selection of other components or materials; de-rating; limiting environmental stresses or operating ranges; redesign of the item to avoid the failure mode; monitoring mechanisms; performing preventative maintenance; or inclusion of back-up systems or redundancy.

S – Severity

Rating S	Criteria: Severity of effect	Consequence	Treatment
10	Death	-	-
9	Quadriplegia	Life-long medical care necessary / coma / permanent damage	Hospital stay
8	Amputations, paraplegia, blindness, deafness, traumatic brain injury (severe), fourth-degree burns	Life-long medical care necessary / coma / permanent damage	Hospital stay

7	Complex fractures, open fracture, inner injuries, traumatic brain injury (severe), third-degree burns	Permanent damage possible	Hospital stay
6	Gash, fractures, torn muscles, articular cartilage injury, traumatic brain injury (moderate), second-degree burns	Permanent damage possible	Hospital stay
5	Gash, fractures, torn muscles, articular cartilage injury, traumatic brain injury (mild), second-degree burns	Reversible injury	Hospital stay or ambulant treatment
4	Severe cuts, severe scratches, severe contusions, strains, first-degree burns	Reversible injury	Ambulant treatment or self-treatment
3	Minor cuts, minor scratches, minor contusions, stiff muscles, tension, blisters, excoriations, sickness, first-degree burns	Discomfort during application up to three days after application	Self-treatment
2	Slight sickness, pressure marks	Discomfort	-
1	No harm	-	-

O – Occurance

Rating O	Criteria: Probability of occurrence
10	Occurs or may occur very likely during every use of the session
9	Occurs or may occur likely during every use of the session
8	Occurs in 1 of 5 sessions (less than once a day)
7	Occurs in 1 of 10 sessions (less than once a day)
6	Occurs in 1 of 50 sessions (less than once half a month)
5	Occurs in 1 of 100 sessions (less than once a month)
4	Occurs in 1 of 500 sessions (less than once half a year)
3	Occurs in 1 of 1000 sessions (less than once per year)
2	Occurrence very unlikely
1	Occurrence nearly impossible

D – Detection

Rating D	Criteria: Likelihood of detection by design control
10	No chance of detection
9	Very remote chance of detection
8	Remote chance of detection
7	Very low chance of detection by indirect methods (hardware or software)
6	Low chance of detection by indirect methods (hardware or software)
5	Moderate chance of detection by indirect methods (hardware or software)
4	High chance of detection by indirect methods (hardware or software)
3	High chance of detection by direct or indirect methods (hardware/software)
2	Direct and indirect detection: Hardware or software

1	Direct detection: Hardware or safe software (category 4, performance level e)

Risk Analysis

Assembly	**Failure & Effect**	S1	O1	D1	**RPN before**	**Preventing measures**	S2	O2	D2	**RPN after**
Connective Cable	The connective cable between the headset and hip belt may cause restricted movement of the user or strangulation.	8	3	5	**120**	Wires are secured to the user's body using body tape or to the user's clothes using Velcro attachments. Wires will be kept close to the body, and not be left hanging loosely to eliminate the possibility of strangulation.	2	2	5	**20**
Phone Temperature	Thermal energy produced by phone may lead to discomfort or, in extreme cases, a low temperature burn.	4	7	3	**84**	Material used in arm set has thermally insulating properties to minimize risk of burn.	2	2	3	**12**
Hip and Arm Set Chafing	Movement may cause friction between the skin and the hip belt and arm set, resulting in abrasion.	3	8	8	**192**	Material used in hip and arm set are non-abrasive to minimize risk of injury. Users are instructed to use anti-friction pads to avoid chafing and discomfort.	2	2	8	**32**
Electric Circuitry	If wires or electronic components are broken or exposed to liquid, the user may experience an electric shock.	4	5	8	**160**	Users are instructed to check the integrity of the components regularly and replace any old wires. Use of water-resistant, insulating, casing minimizes the chance of exposure to liquids.	4	2	8	**64**
Headset edges	The user could cut themselves on the edges of the headset mounting if they are too sharp.	3	4	9	**108**	The headset is designed with curved edges to reduce the chance of injury. All users will be advised to check that their headset does not have any visible sharp edges before wearing it for the first time.	3	2	4	**24**
Visual Overstimulation	The use of an augmented reality display may prove overstimulating,	3	4	8	**96**	A medical professional will be consulted to gauge whether the display could prove harmful. All users will be advised to only use	3	2	8	**48**

Assembly	Failure & Effect	S1	O1	D1	RPN before	Preventing measures	S2	O2	D2	RPN after
	particularly for users with ADHD or varying other disabilities.					the device following an appropriate consultation with a medical professional.				
Obstruction of View	The projection of a visual display in front of the user may result in an obstructed view and pose a danger to navigation.	4	6	5	**120**	The visual display takes up 5% of the user's field of vision and is offset from the user's line of sight to minimize the risk of obstructed view.	4	2	5	**40**

Table 4: Risk analysis

Appendix E – Ethics

Throughout the duration of the project, several ethical considerations were made and incorporated into the design and development process:

- **Respect for colleagues**

To foster a respectful and inclusive working environment, tasks were divided fairly to ensure manageable workloads for everyone. Planning was considerate of each group member's schedule, allowing virtual attendance via Microsoft Teams for members unable to join in person. Everybody reported their weekly progress during the weekly meeting, and all opinions were valued and encouraged. If someone had difficulty with a task, they were offered help and support.

- **Social Responsibilities**

The project's goal was to create an affordable, wearable AAC device for users with CP ensuring that it catered towards an array of physical abilities. The design process considered ways to adapt to differing levels of physical ability at each stage, and focused on how costs could be reduced by customizing components for each user. Ultimately, the project reduces strain on families and carers and improves users' connection with the world and overall autonomy.

- **Legality**

Throughout the process, all relevant regulations were followed to guarantee complete compliance with legal standards. Data security and privacy were ensured by adhering to GDPR regulations while handling any personal information collected during the device's use. Furthermore, to ensure safe operations, the project was created in compliance with all UK laws for product assembly and testing.

- **Respect of Intellectual Property**

All portions of the design idea are original to the design group, and any hardware that was not built by the design group has been referenced appropriately. The original authors of all cited works have been credited to avoid any chance of plagiarism. All copyright laws were respected by not incorporating any copyrighted materials, such as software of eye tracking and IMU coding, without proper authorization or licensing.

- **Non-discrimination**

The design group carefully researched and considered the needs of all users as the product is intended for users with CP with a range of physical ability. Care was taken to ensure varying GMFCS levels were accounted for in the design ideas, and potential other diagnoses or disabilities could be adjusted for on a case-by-case basis. Choice of language within the design description and implementation was evaluated to ensure no discriminatory language was used, and the choice of manufacturing is adjustable to different device sizing to ensure comfort for all users regardless of age or size.

- **Openness**

The dimensions and functions of all hardware including the headset, arm set and hip belt will be instructed clearly to users and carers. The App for IMU data collection on different systems is available to download on smartphones. All pertinent information about the project is shared clearly including data sources, design decisions, and development processes.

- **Human Subject Confidentiality**

When conducting preliminary surveys of AAC user experience, all personal information was kept confidential to guarantee anonymity and privacy.

- **Honesty**

The group ensured that all limitations of the design in its current form are outlined clearly, and any potential safety or functionality concerns are explicitly addressed.

Appendix F – Bill of Materials

Item	Description	Supplier	Quantity	Unit Cost	Cost
Mini 2MP SPI Camera	Eye tracking camera	The Pi Hut	1	£24.00	£24
Raspberry Pi Zero W	Raspberry Pi	Amazon	1	£25.00	£25
Power Bank	Energy cell	Amazon	1	£14.00	£14
Connective wires	Electrical connection between camera and Raspberry Pi	Amazon	1 Single Pack containing 40 wires	£4.29 £0.11 per wire	£4.29
Smart Phone	Incorporated IMU, Wi-Fi connection, speaker	Samsung	1	£99.95	£99.95
3D printed headset frame build	Support the camera and Google Glass	MSk Laboratory, Imperial College London	1 0.00714 cubic meter build with 4 separable components	£36290.63 per cubic meter of the build bounding box + £1 per separable component within the build	£263.21
Google Glass Enterprise Edition 2	Augmented Reality visual display and AAC navigation	Ebay	1	£117.12	£117.12
Hook and Loop Velcro straps	Over the head support of headset frame	Amazon	1	£6.99	£6.99
Adjustable Glasses strap	Behind the head support of headset frame	Amazon	1	£5.99	£5.99
Running Phone Holder	Attachment to hold phone on wrist	Amazon	1	£11.99	£11.99
Bum Bag	Hold the portable charger and raspberry pi	Amazon	1	£6.49	£6.49
SanDisk 256GB Ultra microSDXC card	Micro SD card with Raspberry Pi OS	Amazon	1	£18	£18
Prototype Total Cost				£597.03	
Total Engineering & Development Costs				£627.89	

Table 5: Bill of materials

Appendix G – Nomenclature

AAC – Augmentative and Alternative Communication

Cerebral Palsy – a group of conditions that affect movement and posture. Typically results from damage that occurs to the developing brain, often before birth [3].

GMFCS – Gross Motor Function Classification System: clinical classification used to assess the motor function of individuals with cerebral palsy. Scale ranges from 1-5 (least to most severe motor impairment)

AR – Augmented Reality

VD – Visual Display

UI – User Interface

CAD – Computer Aided Design

TPU – Thermoplastic polyurethane

PSD – Product Specification Document

IMU – Inertial Measurement Unit

Java – object-oriented programming language

Python – object-oriented programming language

XML – Extensible Markup Language; markup language and file format

Gradle – build automation tool for software development, application packaging and deployment

APK – Android Application Package

Kalman Filter – linear quadratic estimation algorithm which can be used to estimate actual inputs when there is systemic noise

TEA – Techno-economic analysis

LCA – Life Cycle Analysis

Appendix H – Selection of AAC Survey Results

Responses from 2 caregivers of AAC users:

Assessment of personal AAC device (1 eye-tracking respondent, 1 partner-assisted auditory scanning respondent):

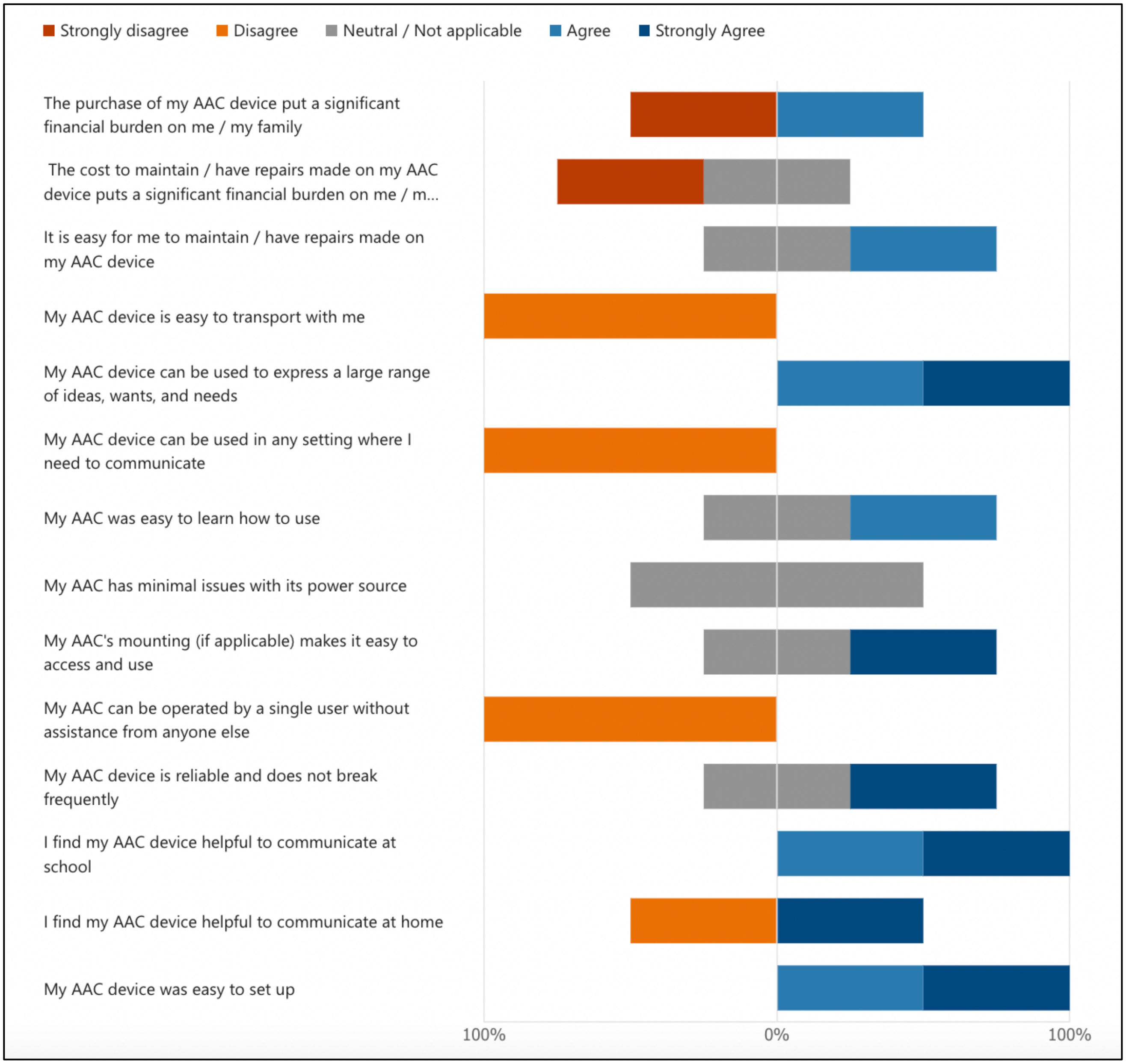

Figure 15: Responses from caregivers of AAC users

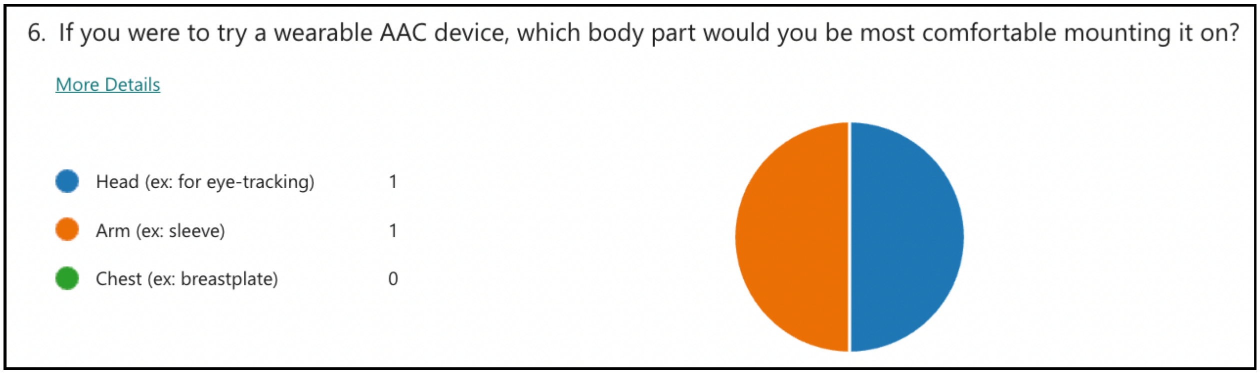

Figure 16: Responses from caregivers of AAC users - continued

Responses from 9 Pace Centre staff who work with AAC users:

Evaluation of eye tracking AAC technology (7 respondents)

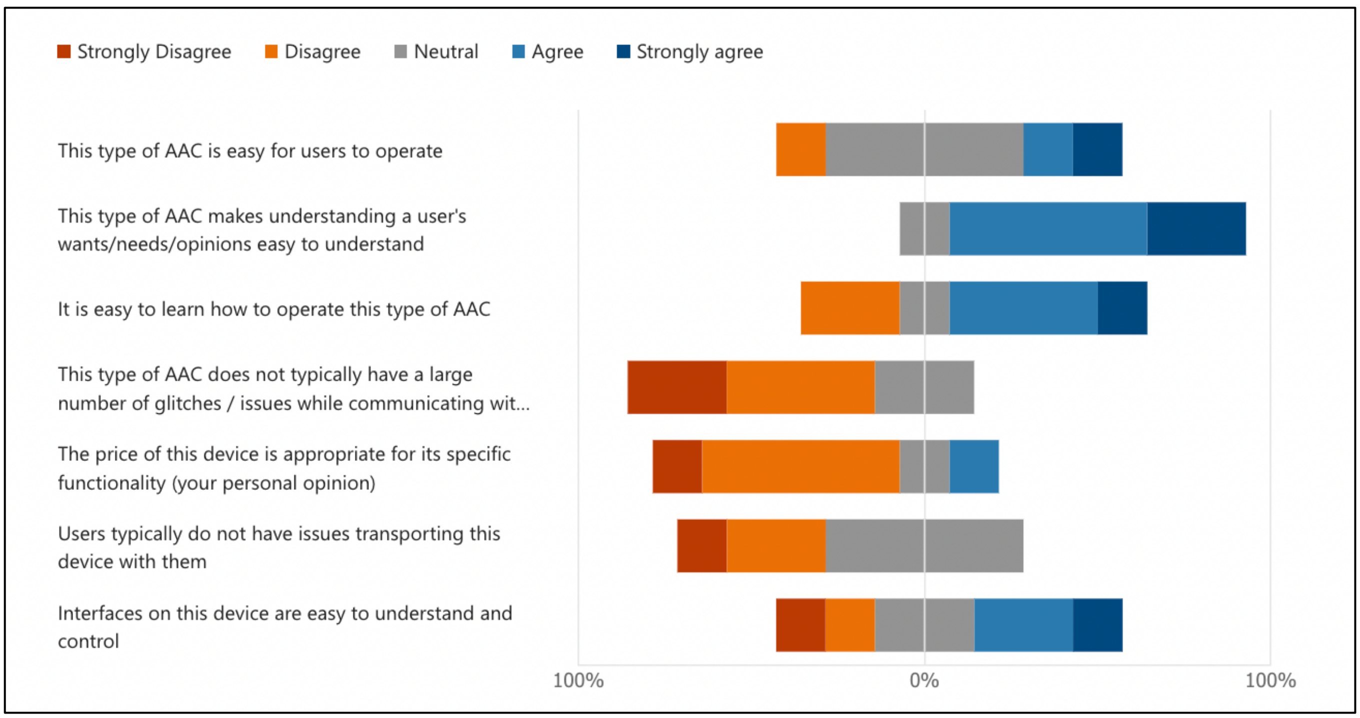

Figure 17: Evaluation of eye tracking technology

Assessment of wheelchair mounted AAC (7 respondents):

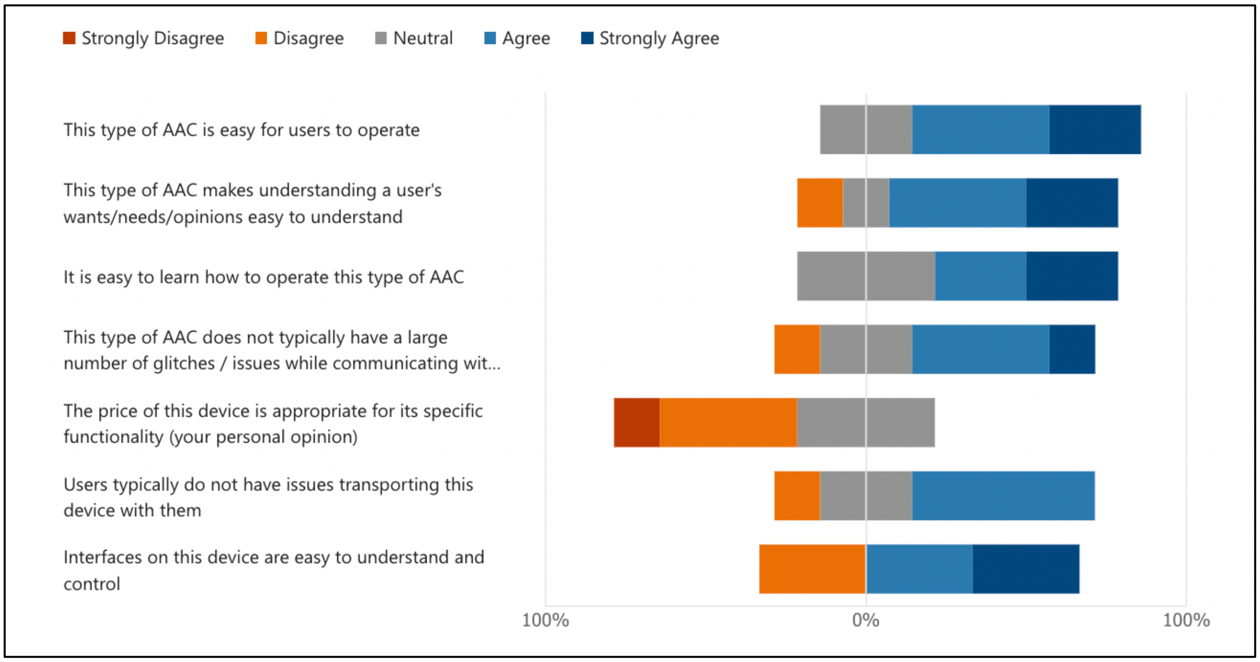

Figure 18: Assessment of wheelchair mounted AAC

Assessment of potential improvements to AAC (9 respondents):

19. If there is one thing you could change about current AAC devices today, what would it be?

9 Responses

ID ↑	Name	Responses
1	anonymous	Ease of access and price
2	anonymous	(Not sure if this available). Make AAC apps that can be use on mainstream tec. So AAC can be introduced and practice at a very early stage (i.e 2 symbols) and is available to all.
3	anonymous	They would be more affordable and accessible to all
4	anonymous	the eye tracking AAC often glitches or takes time to re-calibrate. It can be exhausting when using an eye gaze
5	anonymous	A better understanding that digital AAC is not a magic wand that will allow someone access to an internal store of language - it is like learning a different language and takes time, effort and ongoing adaptation
6	anonymous	more user friendly
7	anonymous	Some are heavy and often difficlt to move between communication packages and other software on the device.
8	anonymous	Make more portable and universally mountable. Make more useable outdoors. Incorporate predictive text earlier in AAC journey.
9	anonymous	Improve on the battery life

Figure 19: Assessment of potential AAC improvements

Appendix I – Detailed Testing

Eye tracking: ***(tested using computer)***

Assessment Points	Method	Result
Does the software require both eyes for eye tracking?	Volunteers were instructed to use the eye tracking, with one or both eyes centered on the camera and the results were assessed.	Both eyes are required to successfully use the software.
Sensitivity	Volunteers were asked to use eye tracking and move their heads and eyes randomly. Program response was assessed to determine whether the cursor moved immediately when they moved their eyes and head.	At present, the movement distance that the eye can constitute is too small and requires the assistance of head movement or editing of the code to increase sensitivity.
Accuracy	Volunteers were asked to use eye tracking and were asked to look at a certain point on the screen. Assessment was made regarding whether the cursor and the point finally coincided.	Where the user focusses on the screen, the mouse will follow, but assistance may be required from the IMU or head movement. The mouse may shake due to noise interference.
Room lighting requirements	Change the lighting conditions on volunteers' faces and have them test whether the code works properly under different light intensities	If there is sufficient lighting for facial contours to be illuminated, the camera will recognize the information around the eyes and the program can run successfully.
Effectiveness with prescription lenses	Ask volunteers to try on glasses with lenses and test whether the code successfully recognizes faces when they do so, comparing the results with those without the glasses.	The program can accurately identify the position of the pupil without being affected by glasses or other facial accessories
Latency	Record the time taken between the movement of the eyes and the movement of the cursor, by means of frame-by-frame video analysis or other suitable method.	Incomplete Testing

Table 6: Detailed eye tracking testing

Motion Sensing Testing: ***(tested using computer)***

Assessment Points	Method	Result
Steady state performance	Place the phone steady on a horizontal flat table and analyze cursor performance.	The cursor stays stationary, which is valid since there is no linear acceleration in any direction.
Kalman Filter Range & Input Noise Removal	Test different value for measurement variance in Kalman filter coding, to see how it performs in removing noise	The number chosen is 1e-6. Relatively accurate, but there may be problems with people who have muscle spasm.
Reaction time	Using a stopwatch, perform repeated tests of the time taken from the beginning of motion until the cursor displacement matches the motion.	Once motion sensing starts, it takes 2-3 seconds at the beginning of motion for the program to work accurately.
Non-stationary accuracy	Perform repeated tests of the accuracy of cursor motion when user is not staying still. Assess for success rate of hovering the cursor over a specified target point.	Incomplete Testing
Comfort	Survey a range of users with and without disabilities regarding the comfort and fit of the arm band. Measure the weight of phone, evaluate according to user's muscle strength, consulting a licensed physiotherapist.	The armband length can be adjusted to fit different thickness. No user surveying has taken place yet, and no professional consultation has occurred.
Duration and safety	Test the maximum screen time of phone when motion sensing is on and use thermometer to measure the phone's temperature throughout the process	Phone screen can be on for more than 5 hours. Phone becomes noticeably warmer but no formal testing with thermal measurements has been completed yet.
Required range of motion	Ask volunteers to move the phone left, right, up and down and measure the relative displacements of the cursor on the monitor. Assess what range of motion is required to create a full range of cursor positions.	Incomplete Testing

Table 7: Detailed motion sensing testing

Visual Display Testing (Android Application):

Assessment Points	Method	Result
Application Deployment	Test for full deployment of application without wire connection to the computer.	The application does not yet deploy fully and requires a wire connection to Android Studio to maintain function.
Battery life	Run google glass until out of charge and record time.	Incomplete Testing
Varying Wi-Fi strength	Test the speed of the Google Glass using different Wi-Fi strengths.	Incomplete Testing
Bluetooth inputs	Connect multiple devices and multiple types of devices at once.	Incomplete Testing
Compatibility	Check if google glass will run with a range of web-based applications, not just the Pace Centre My Way App.	5 different websites all opened within the application VD successfully.
Security	Utilize Quick Android Review Kit to assess application security	Incomplete Testing
Compliance	Conduct GDPR Compliance Test	Incomplete Testing

Table 8: Detailed visual display testing

Mechanical Testing:

Frame sturdiness	Headset frame without attachments dropped from a height of 2m in accordance with PSD specifications [11].	Assembled frame is intact and undamaged after a drop from 2m
Headset assembly sturdiness	Full headset assembly dropped from a height of 2m according to PSD specifications [11].	Incomplete Testing
Compatibility with Prescription Lenses	Consult with lens manufacturers to verify compatibility of lens frames with specialized prescription lenses	Incomplete Testing
Frame deformation	Bridge deformation testing of glasses frame carried out to test for potential long-term frame damage from headset component weight	Incomplete Testing

Table 9: Detailed mechanical testing

Selection code: ***(tested using computer)***

Assessment Points	Method	Result
Adjustable time-based selection	Volunteers were instructed to hover the cursor over the button, with a time needed for selection of 1 second, 3 seconds and 10 seconds (after timer was adjusted within the program).	Changing the time reliably changed the taken for the button to be selected.
Accuracy	Volunteers were asked to hover the mouse close to, but not over, the button for more than 3 seconds. Then, they were asked to hover the mouse over the button for more than 3 secs.	The audio was not outputted when the mouse was not over the button, and outputted when it was.
Reliability	Volunteers were asked to hover the mouse of the button for more than 3 seconds 10 times.	Each time, the audio was outputted after 3 seconds was outputted.
System testing	Volunteers were asked to hover the cursor over the button for more than 3 seconds using, first, eye-tracking and then the IMU.	Results were the same for the eye-tracking and the IMU – as long as the cursor was over the button for 3 seconds, the audio was outputted.

Table 10: Detailed selection code testing