Pupl: The Pupillometer App
Final Report

Apper: Lisa Ye 997792731
Programmer: Clyde Wheeler 1001799128
Programmer: Shawn Wiebe 1001736302

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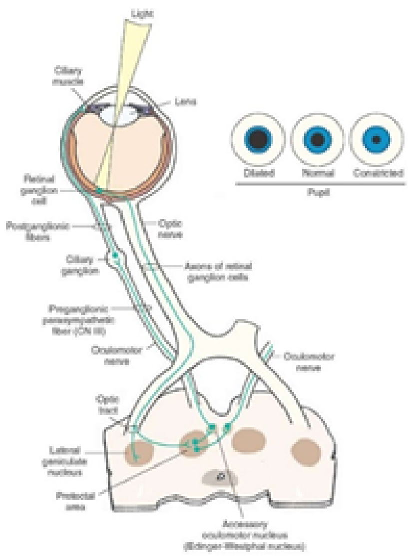
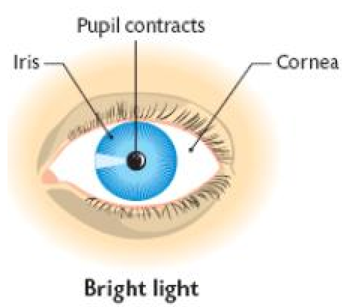
1. Introduction

The goal of Pupl is to aid clinicians in conducting neurological assessments of patients. In a hospital setting, neurological assessments are performed routinely depending on the acuity of the patient (e.g. every 1 to 4 hours per patient). Neurological assessments consist of the Glasgow Coma Scale and pupillary light reflex test, which enables clinicians to infer whether any neurological issues require further medical attention. The GCS score is used as an objective measurement of responsiveness that enables clinicians to quantify a patient's level of consciousness (Image 3).





Glasgow Coma Scale

BEHAVIOR	RESPONSE	SCORE
Eye opening response	Spontaneously	4
	To speech	3
	To pain	2
	No response	1
Best verbal response	Oriented to time, place, and person	5
	Confused	4
	Inappropriate words	3
	Incomprehensible sounds	2
	No response	1
Best motor response	Obeys commands	6
	Moves to localized pain	5
	Flexion withdrawal from pain	4
	Abnormal flexion (decorticate)	3
	Abnormal extension (decerebrate)	2
	No response	1
Total score:	*Best response*	15
	Comatose client	8 or less
	Totally unresponsive	3

Image 1 (left): The pupillary light reflex pathway
Image 2 (middle): The pupil constricts in reaction to bright light
Image 3 (right): Standardized GCS scoring

The pupillary light reflex is when miosis (pupil constriction) occurs as a reaction to light (Image 1 and 2). This reflex is the body's natural response to bright lights and its purpose is to prevent excessive stimulation of the optic nerve that could lead to temporary visual deficits. Neurological issues can be inferred from its result (i.e. a sluggish response may indicate that the patient is undergoing cerebral edema or herniation). Measurement and tracking of the pupil size over time can also inform clinicians about neurological status (e.g. pinpoint pupils may be indicative of an opiate overdose or a pontine hemorrhage stroke).



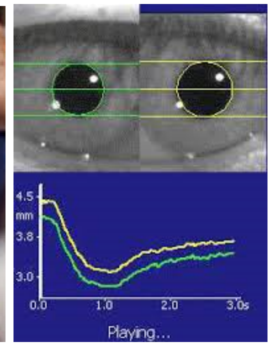


Image 4 (left): Manual pupillary light reflex with flashlight
Image 5 (middle): Neuroptic NPI Pupillometer device
Image 6 (right): NPI Pupillometer Display

Basic methods of assessing the pupillary light reflex use a flashlight and involves the clinician's subjective assessment, while advanced methods involve expensive and specialized medical equipment (e.g. Neuroptic NPI pupillometer, Image 5 and 6). With an accessible and accurate app to track changes in the aforementioned neurological assessment components detected by Pupl, clinicians can save lives by initiating earlier treatment [2]. Pupl also has broader potential in healthcare applications for the research of depression, Alzheimer's, sleep, diabetes, multiple sclerosis and other diseases [1].

2. Overall Design & Functionality

Pupl was designed to replicate the neurological assessments that are regularly conducted by clinicians in the hospital. Pupl fits into a clinician's workflow almost seamlessly; in the same way a clinician would pick up and fill a patient's chart following a GCS assessment, the clinician selects the patient, enters the 'Test Centre' and inputs GCS results followed by performing the pupillary light reflex test. The Neuroptic NPI Pupillometer, a pupillometer device used in hospitals, influenced the visual layout of the pupillary light reflex implementation. The block diagram, below, displays the high level relationship of Pupl's various components and will be discussed in itemized detail below.

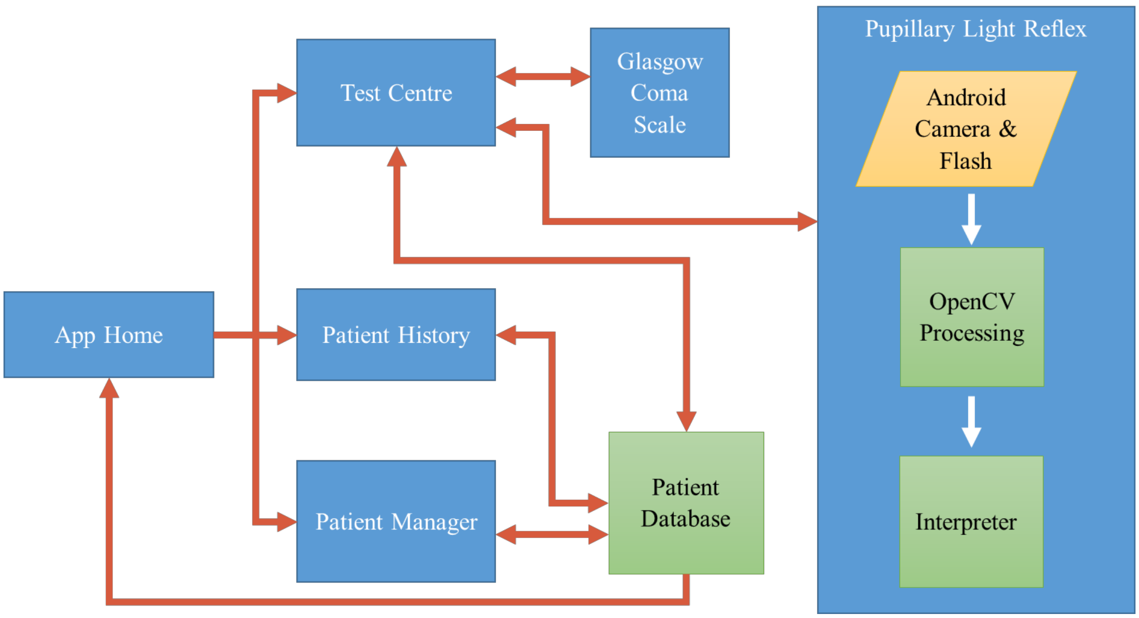


Figure 1: High level block diagram of Pupl's functional components.
Blue = GUI, Green = Background Process, Yellow = Hardware.

App Home is the primary screen that allows users to navigate to the various functional areas of the application ('Test Centre', 'Patient History' and 'Patient Manager'). It populates a drop-down menu from the patient database to facilitate quick patient selection.

Test Centre allows the user to navigate between the neurological assessment components (GCS and pupillary light reflex). When the user leaves the Test Centre, it saves all results to the database.

Glasgow Coma Scale facilitates entry of the GCS scores.

Pupillary Light Reflex facilitates the pupillary light reflex using the device camera and flash. It does this by recording a video of the eye, during which, the phone's flash will turn on for 1 second to stimulate the reflex. Then the video is processed, and the results of the processing are displayed back to the user.

OpenCV Processing is the primary processing block of our app. It takes the recorded video frame-by-frame and determines the size of the pupil in each, the framerate of the video is then used to calculate the speed of constriction.

Interpreter is an algorithm that assigns a qualitative value of “Brisk”, “Sluggish”, or “Absent” to describe the constriction speed of the pupil.

Patient History is a user interface component that displays the selected patient’s past test results in a timestamped table with a plot of the data shown above. The results for GCS, pupil size, and pupillary reflex speed are on separate pages.

Patient Database is where all the data is stored and where it is retrieved from.

3. Statement of Functionality

All of Pupl’s features, described above, are functional as intended and are described in more detail below.

A. User Interface and Patient Management

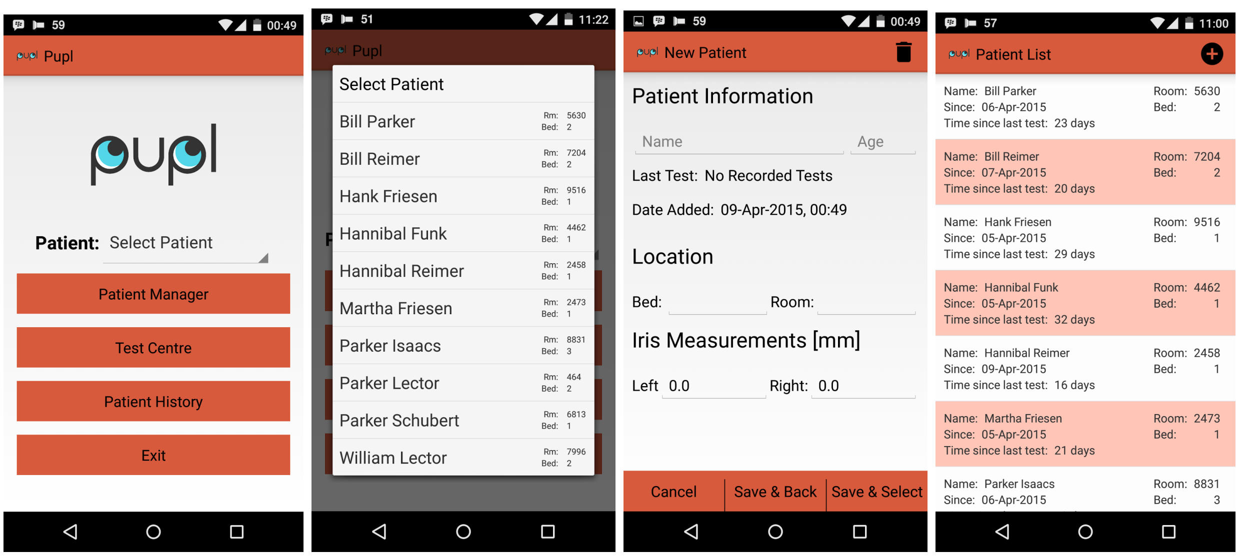


Figure 2: User interface screens, from left to right: main menu, patient manager, new patient dialog, and drop down patient selection dialog.

When the user launches Pupl, they are greeted with the main menu. If they attempt to start a test without selecting a patient, they will be instructed to do so. The user can create or edit patient information in the patient manager (Figure 2).

B. Glasgow Coma Scale (GCS) Test

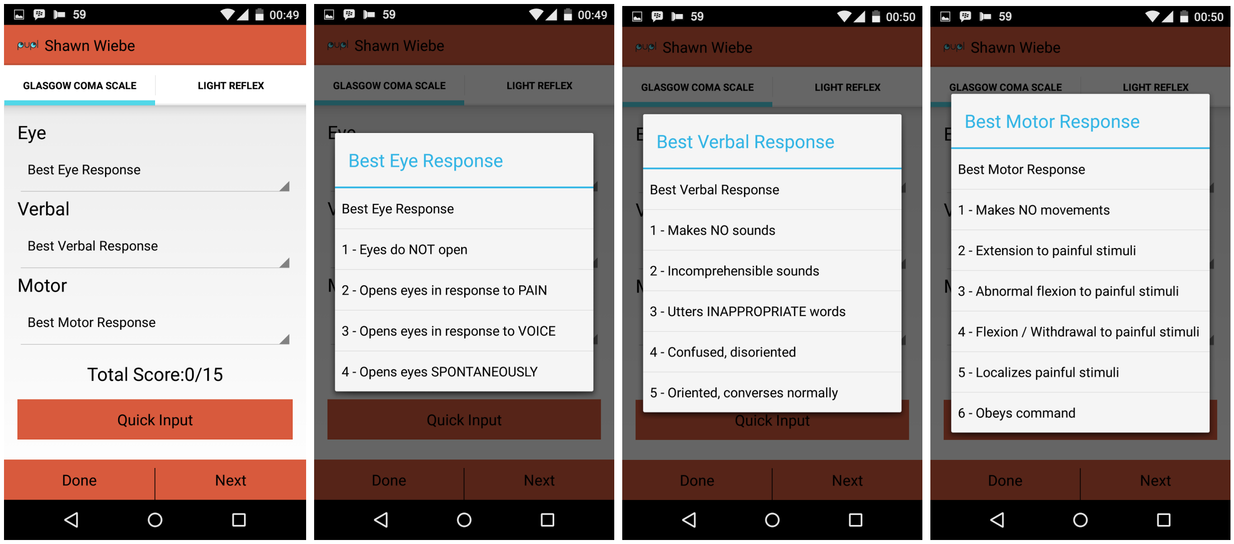


Figure 3: The GCS test interface (left) and input dialogues (right).

The GCS test page provides a way for the user to score the patient's responses following an assessment. The user can individually select each pop-up spinner, or press the "Quick Input" button (Figure 3). "Quick Input" automatically opens the next input window, reducing the number of selections the user has to make from 6 to 4, improving the user experience.

C. Pupillary Light Reflex Test

The pupillary light reflex test measures the size (diameter) and constriction speed of the patient's pupil, and classifies this constriction speed into one of three categories: brisk, sluggish, or absent.

The user is prompted to fit a red circle over the patient's iris. The red circle defines the region that will establish a reference scale that is used to translate the pupil's size to an absolute measurement in millimeters (assuming the iris size is 12 mm; average human iris size [6]).

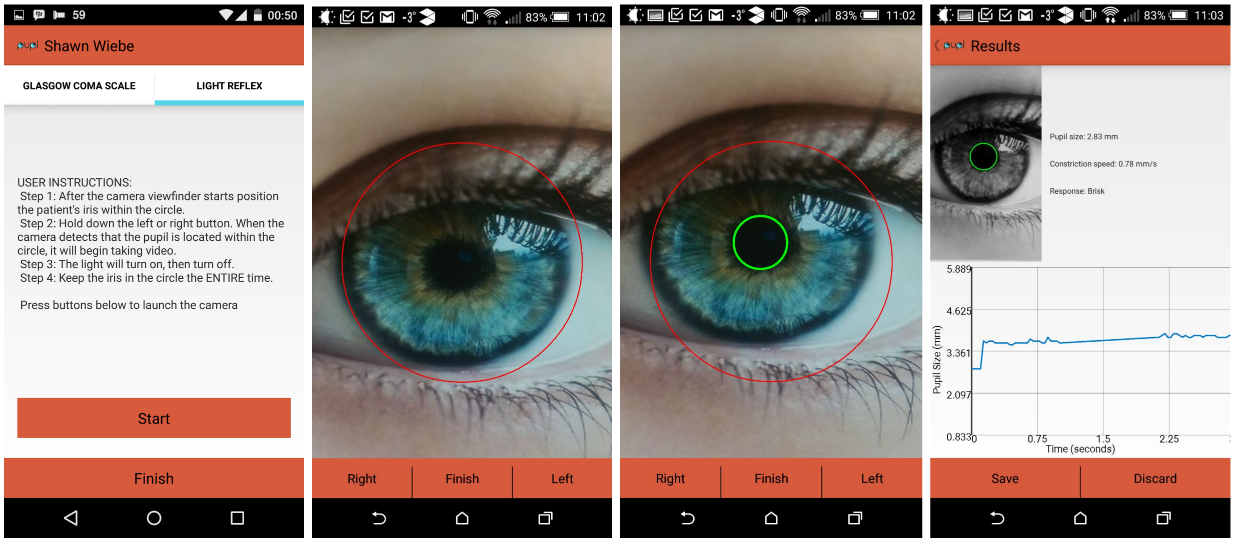


Figure 4: From left to right: the pupillary light reflex test instruction screen, a patient's iris fitted to the red iris circle, pupil detected during the test, and the results screen from the light reflex test.

Next, the user will press and hold the button corresponding to the eye of interest. This initiates pupil detection, which finds the pupil and fits a green circle to it, displayed to the user. Once the user is confident that the patient's pupil has been found, the button is released, starting the pupillary light reflex test. This starts a video recording, during which the flash is turned on for one second.

Then the video is processed offline, measuring the size of the pupil in each frame. The constriction speed is measured by comparing the size of the patient's pupil before and after the flash. After processing, a results screen is shown, which displays a video playback of the test and a report of the patient's pupil size and constriction speed (Figure 4). It will also grade the constriction speed as described above. A graph plotting the pupil size over time is also shown in order to provide more feedback to the user.

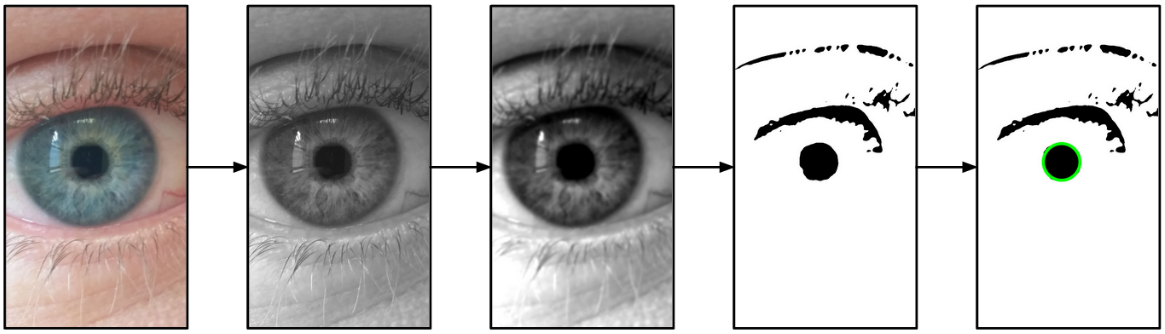


Figure 5: Image processing technique isolate and finds the pupil in each video frame.

The pupil detection algorithm used by Pupl is depicted graphically in Figure 5. The frames recorded by the user's device are first converted to grayscale, stretched in contrast, and then thresholded [4]. The resulting image is then searched for contours, one of which is assumed to be the pupil. The pupil is found by examining the size, position, area, and aspect ratio of each of these contours, knowing that the patient's pupil is circular and should be near the centre of the red circle.

D. Patient History

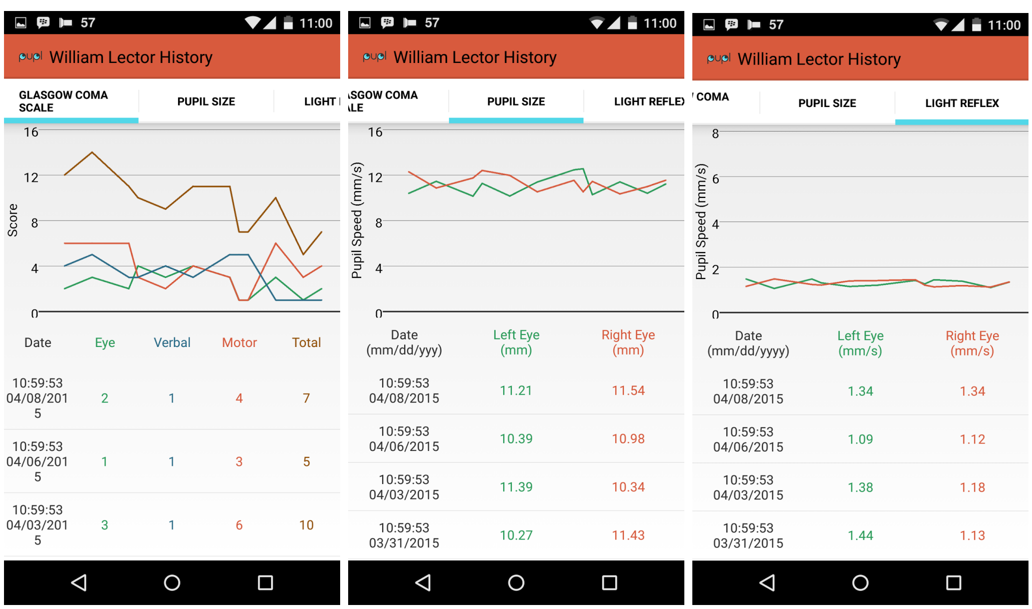


Figure 6: The patient history screen - view past patient test results. These results are graphed over time so that progress can be quickly assessed.

The patient history activity reads the selected patient's past test results from the database and displays them in an understandable manner. As can be seen in Figure 6, there is a page for GCS, Pupil Size and Light Reflex results. Each page displays past results in two ways, via a line-plot as well as in a vertically scrollable list of text-values. In addition, touching the column headers will cause the line-plot to display only that column's information, touching the "Date" column will add all lines back to the plot.

4. Lessons Learned

Pupl was a great learning experience for the whole team. We learned about the value of the spiral process, and the value of directed meetings and explicit deadlines. As a team, we worked very well together, with each member contributing ideas, time and effort to the success of our Android application.

We learned the shortcomings of using visible light for pupillary light reflex. If capturing the light reflex video in a dark environment, the automatic gain of the camera is too slow to adjust to the sudden flash, causing a white-out. During this white-out period the pupil is constricting and we are unable to identify the pupil, rendering the test ineffective in dark environments. In addition, glare reflected from lighting had a negative influence on our ability to detect the pupil. Neuroptic's NPI Pupillometer uses the infrared spectrum to conduct the pupillary light reflex, which helps it avoid our issues, as the visible light that causes the pupil to shrink has no effect on the captured video.

Image 7 (left)**:** Our team testing the Neuroptic NPi-100 Pupillometer on site at St. Michael's Hospital
Image 8 (right)**:** A dark brown iris imaged in infrared

Overall, we are satisfied with the product we developed. We spent a lot of time thinking about how this app would be used by clinicians before we started development. However, before releasing our app we want the 'Pupillary Light Reflex' test to achieve more consistent results. As mobile phone technology advances, eg. development of RGBi cameras that are capable of capturing in the infrared spectrum, it will greatly improve our ability to conduct the pupillary light reflex.

5. Contributions

Lisa:
- Provided ideas for useful mobile applications in healthcare
- Helped make decisions about layout and interface so that it would be intuitive to use and work well with real life workflow when clinicians are caring for patients
- Reviewed the literature on automated pupillometry vs. manual examination in clinical settings
- Provided access to a Neuroptic NPI Pupillometer for user testing at St. Michael's Hospital
- Connected our team with the Neurosurgery Clinical Nurse Educator
- Acted as a test subject for app testing for dark irises

Clyde:
- Implemented the pupillary light reflex test and results screens
- Designed the pupil finding algorithm using OpenCV
- Implemented video recording and offline processing functionality
- Designed the pupil reactivity grading algorithm based on the literature
- Communicated with NeurOptic to obtain quotes for their NPi-100 device
- Commissioned a graphic design student to design the Pupl logo and theme

Shawn:
- Implemented SQLite Database (structure as well as storage and retrieval functions)
- Implemented ListView adapters to format database information to be readable
- Patient Manager Implementation - layout, functionality, database communication
- App Layout/Navigation - initialized general navigation and layouts for most screens
- GCS Test - implemented dropdown menus and Quick-Test functionality
- Implemented Patient History - layout and functionality, with column-header selectable lines

6. Apper Context

The development of a mobile app that can accurately measure the pupillary light reflex has great potential for clinical use due to the value of objective assessment data when making medical treatment decisions. Assessing a patient’s GCS and their pupillary light reflex is part of the standard neurological assessment performed by clinicians on a daily basis. Changes in GCS and pupillary light reflex are important indicators of acute neurological deterioration, which would indicate the need for additional medical treatment.

Current practice most commonly involves the use of a flashlight to observe the pupillary light reflex. The clinician makes subjective assessments about the pupil size and the speed of constriction despite research showing that manual pupillary examination often results in interobserver discrepancies and errors depending on the working conditions. [3] In some specialized ICU settings, pupillometer devices using infrared technology may be available, but they are expensive and not readily available (e.g. $6600 per unit).

Further, the GCS test feature within the app is also useful on its own as a teaching tool for healthcare professionals. There are few mobile apps available on the Google Playstore that offer GCS scoring, but Pupl offers better user experience, intuitive interface and the added ability to store scores.

Before Pupl can be used in clinical practice, further research and testing is required in order for it to be validated. It is our hope that this mobile app can be an inexpensive and accessible replacement for subjective tools and a replacement for expensive advanced equipment. Research supports the benefits of using a pupillometer to assess pupillary light reflex, but clearly states the need for more robust research to be done in clinical settings before it can replace manual assessment [3]. Furthermore, there are studies that demonstrate additional uses for a pupillometer, including uses in the research about diabetes, Alzheimer’s, and many other pathologies [1]. Therefore, Pupl is the first mobile application of its kind with the ability to perform complex neurological assessment and provide objective results without the need for additional specialized hardware.

7. Future Work

A. Refine & Perfect Pupil Recognition

Before Pupl can be reliably used in a hospital setting, its pupil detection algorithm must be improved to the point that it will function even in suboptimal conditions such as poor lighting, or on patients with dark irises. This might necessitate the use of lenses, cameras, or lights that are external to the user's device.

B. Validate Algorithm for Grading Pupil Reactivity

The algorithm for grading pupil reactivity (e.g. brisk, sluggish, absent) is current based on a single policy bulletin paper [5], therefore further research and testing on patients with neurological disorders or brain injuries is required to strengthen and validate the algorithm.

C. Comprehensive Statistics

Pupl currently displays past patient results in a simple line graph format, as can be seen in Figure 6. Other data visualisation and statistical processing techniques should also be explored in the future, as they may provide the user with more insight regarding the patient's health.

D. Clinical Decision Support

Once the algorithm for grading pupil reactivity becomes more robust, there is great potential for building clinical decision support aids within the app. For example, based on the tracked changes in GCS and pupil reactivity, the app can alert clinicians about critical changes that require additional medical attention and alert the need to notify a physician or the need for a CT scan. This added functionality would be valuable for nurses, nurse practitioners, physicians, and for new learners of the neuroscience field.

E. Secure Hospital Server Integration

Currently, Pupl stores all test results on the user's device, which would then need to be manually transferred to hospital database servers. An improvement upon this would be to store these test results directly on hospital servers, improving the overall user experience, and also reducing risk of exposing a patients medical records due to the loss or theft of the user's device.

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