Device Monitors Head Angles Linked with BPPV

Timetable (School-Wide Science Fair):

Date	Milestones
Dec.18 - 31	• Background information/research about the topic ○ What is vertigo? ○ What are the roles of the ear and the brain in the vestibular system and how do they work? ○ How does the vestibular system keep balance and when is it broken? ○ What is the Epley Maneuver?
Dec.31 - Jan.3	• Put research into online presentation (Google Slides/Powerpoint) ○ This should be the first half of online presentation, still need to account for the model and experiment
Jan.3 - 17	• Build physical model ○ Include a way to read the angle of device
Jan.17 - 31	• Conduct experiment • Record results and information about the device on the slideshow ○ This should be the second half of the presentation • Record presentation for online science fair

Problem (Dec.18):

Can real-time feedback from an accelerometer detect head-tilt angles related to BPPV?

Background Research:

Dec. 20:

Vertigo is a symptom that creates a false sensation that you or your surroundings are constantly spinning or in motion. It occurs when there is a mismatch between signals from various components of the vestibular system, leading the brain to misinterpret body positioning and movement.

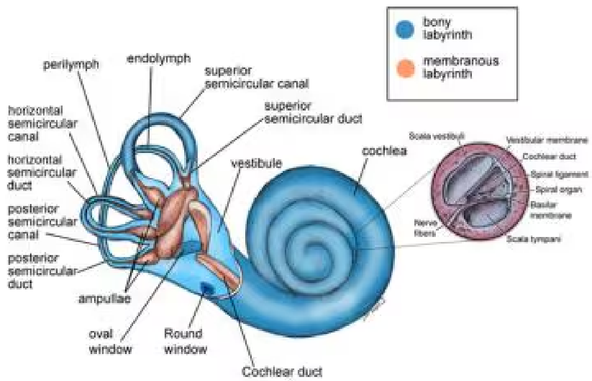
Common symptoms include:

- Dizziness/spinning sensation
- Issues regarding balance
- Nausea and vomiting
- Motion sickness
- Headaches
- Hearing loss

The vestibular system is located in the inner ear and brain of the ear and brain, and is one of three main systems that help maintain your orientation, which also include the visual system (eyes) and the somatosensory system (muscles and joints). The ear detects head movement and sends signals to the brain to interpret them. The vestibular system is split into two main functions, which are the peripheral and central systems:

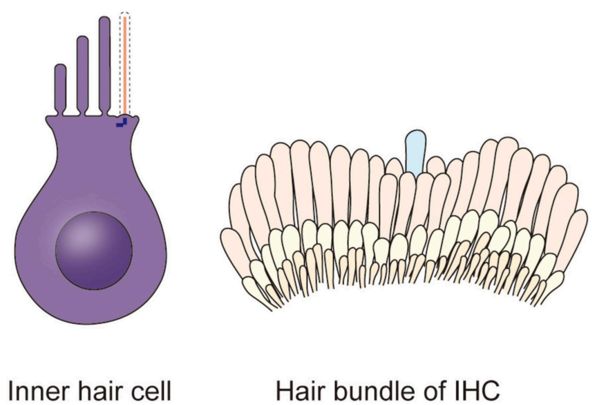
The peripheral vestibular system is located in the inner ear, in the vestibular apparatus. It consists of five main organs.

  - Semicircular canals: The semicircular canals are made of three tubes, which detect head movements. They are the superior (up and down), horizontal (left to right), and posterior (side to side/angled) canals.
  - Otolith organs: The other two organs are the otolith organs. They detect linear movement, which are affected by forces such as gravity and velocity. The utricle detects motion occurring when the body is moved horizontally (back and forward) while the saccule acts during vertical movement.



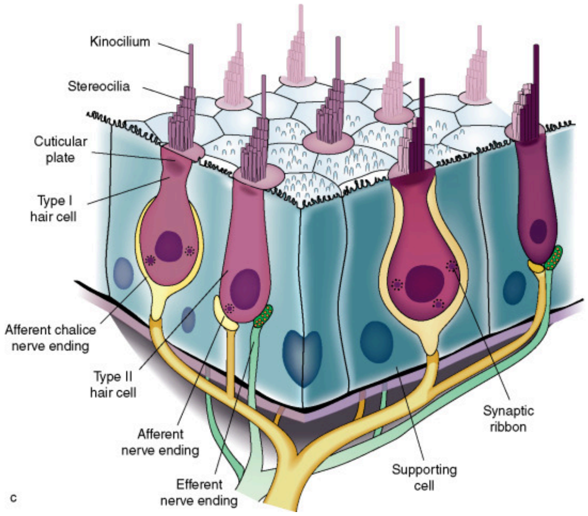
Dec. 21:

Head movements trigger the movement of endolymph, a fluid found throughout the semicircular canals and otolith organs. As the head changes position, the fluid shifts, bending microscopic hairs on hair cells.

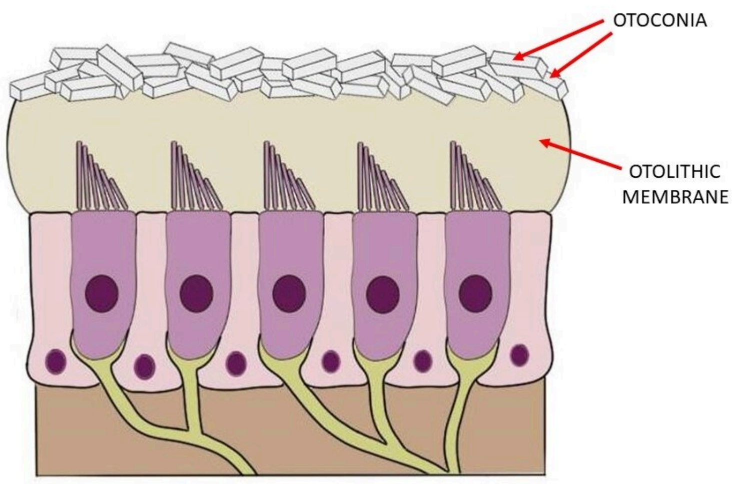


In the semicircular canals, the movement of endolymph will detect head movement, while in the otolith organs, tiny calcium carbonate crystals called the otoconia bend the hairs due to a shift in gravity or acceleration. This helps the utricle and saccule detect the body’s linear movement. When the hairs are bent, the hair cells will open ion channels to regulate the cell’s electrical signal, sending electrical signals to the brain through the vestibular nerve in return. The brain deciphers these signals to determine the body’s position and orientation.

Semicircular canals:



Otolith organs:



The vestibular nerve connects the inner ear to the **central vestibular system,** which consists of the brain and associated nerves. The brain interprets signals sent from the inner ear through the vestibular nerve about head position and linear movement. Using this information, the brain sends signals to the eyes and spinal cord to maintain balance and posture.

Dec. 31:

Benign Paroxysmal Positional Vertigo (BPPV) originates inside the inner ear. It occurs when otoconia, the tiny calcium carbonate crystals normally located in the utricle and saccule, become dislodged and move freely within the inner ear. When the otoconia crystals enter parts of the semicircular canal (most commonly the posterior canal), they interfere with the ear's function of detecting head movement, causing incorrect signals to be sent, resulting in vertigo-like symptoms.

BPPV is highly treatable, especially due to the Epley maneuver. This treatment is conducted by a healthcare professional, who guides a patient through specific head angles and positions. These movements allow gravity to shift the crystals back into their original position, relieving the symptoms associated with BPPV.

Although BPPV is considered less harmful and responds to treatment, it is also the most common form of vertigo, over other types of vertigo that start in the inner ear (such as Meniere's disease, vestibular neuritis). It occurs prominently in older adults, especially those over the age of 50, and often recurs in individuals who have previously experienced it. Certain head positions can cause the loosened otoconia to shift, leaving the utricle once again.

Jan. 4:

Application:

The health risks associated with the recurrence of Benign Paroxysmal Positional Vertigo can be addressed through an accelerometer that monitors a user's head position. This device would alert the wearer when their head stays at extreme angles for a long duration of time, typically positions that are more likely to dislodge otoconia in the inner ear and trigger vertigo.

Problem:

Can real-time feedback from an accelerometer detect head-tilt angles related to BPPV?

Hypothesis:

If a head-position device is used to detect head-tilt angles associated with BPPV, **then** it will accurately detect the angles during participant movements, **because** its sensors track tilt continuously, identifying positions that could trigger vertigo.

Jan. 5:

- Created presentation
    - Need to fill up with information now

Jan. 6:

- Searched for accelerometer (MPU 6050) for device
- Found tilt sensor, but it will not work with my project

Jan. 8:

- Began working on first half of the presentation
  - Got all info for "background research" but still need to finish associated slides

Jan. 9:

- Completed "background research"
- Completed "application" and setup for future slides

Jan. 11:

Procedure:

1. Set the device at 0º on a flat surface.
2. Move the device slowly, checking the angle at -90, -60, -30, 0, 30, 60, and 90 degrees.
3. Hold the device position for 5 seconds.
4. Record the angle measured by the device on a datasheet.
5. Measure the device's angle with a leveller on a phone.
6. Return the device to 0º and reset it for accuracy.
7. Repeat steps 4-7 two additional times for the same angles (3 trials in total).
8. Repeat steps 3-8 for the remaining angles.

- The "procedure" slide has been created and filled out in the slideshow
- The "experimental design" slide outlines what the experiment covers and introduces the variables:

Variables:

<u>Independent:</u> Angle of tilt.
<u>Dependent:</u> Angle detected by the device (degrees).
<u>Controlled:</u>

- Tested on the same surface
- Same duration holding each angle
- Same reference tool for reference angles

Jan. 12:

- Used Wokwi simulator for device testing before building it physically

- Today's code:
    - This code will tell us what the x, y, and z angles are of the accelerometer in the serial monitor (online)

```
#include <Adafruit_Sensor.h>
#include <Wire.h>
#include <MPU6050_light.h>

MPU6050 mpu(Wire);

void setup() {
Serial.begin(115200);
Wire.begin(); //initalize connection between microcontroller and sensor
mpu.begin(); //initialize mpu (sensor)
mpu.calcOffsets(); //define original positon - will remember this as 0
degrees for code
}

void loop() {
  mpu.update();
  float angle[3] = {mpu.getAngleX(),
                    mpu.getAngleY(),
                    mpu.getAngleZ()};
Serial.print("[");
  Serial.print(millis());
  Serial.print("] X: ");
  Serial.print(angle[0]);
  Serial.print(", Y: ");
  Serial.print(angle[1]);
  Serial.print(", Z: ");
  Serial.print(angle[2]);
  delay(500);
  }
```

Jan. 15:

- Bought sensor today, this code works on the simulator (although the angle keeps on growing possibly due to simulator settings) so hopefully it will work on the sensor once it arrives
- Today's code:

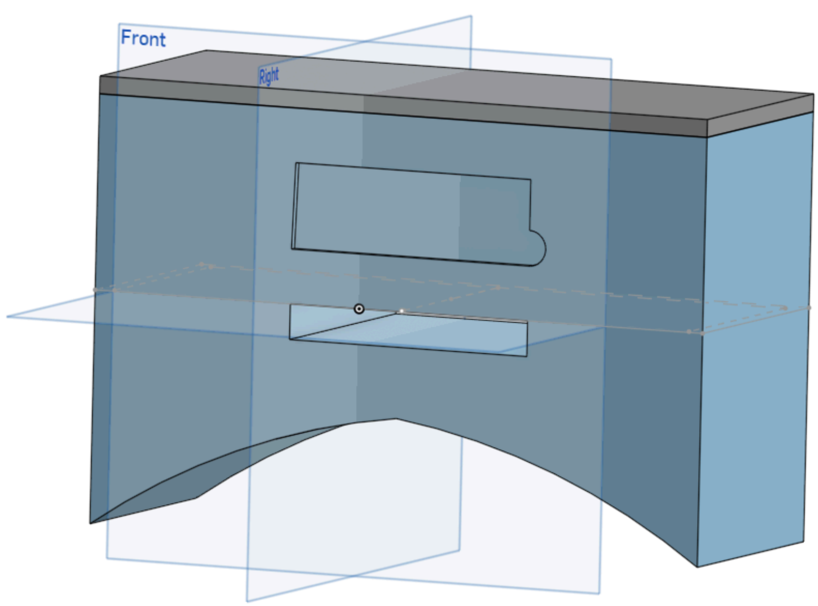
- This code includes the LCD monitor, which will be used in the device to display what angle it reads
- Some of the code has been commented out, as I will not be using the serial monitor for this experiment

```
#include <Adafruit_Sensor.h>
#include <Wire.h>
#include <MPU6050_light.h>
#include <LiquidCrystal_I2C.h>


MPU6050 mpu(Wire);
LiquidCrystal_I2C lcd(0x27, 16, 2); // defining lcd object - 0x27 = 
address, 16 = columns in lcd, 2 = rows in lcd
unsigned long timer = 0;

void setup() {
Serial.begin(115200);
Wire.begin(); //initialize connection between microcontroller and sensor
mpu.begin(); //initialize mpu (sensor)
mpu.calcOffsets(); //define original position - will remember this as 0 
degrees for code
lcd.init();
lcd.backlight();
}


void loop() {
  mpu.update();
  float angle[3] = {mpu.getAngleX(),
                    mpu.getAngleY(),
                    mpu.getAngleZ()};
//Serial.print("[");
 /* Serial.print(millis()); will not be using serial monitor as much, if I 
want to see x, y, and z angles on monitor uncomment
  Serial.print("] X: ");
  Serial.print(angle[0]);
  Serial.print(", Y: ");
  Serial.print(angle[1]);
  Serial.print(", Z: ");
  Serial.print(angle[2]);
```

```
  delay(500);*/


if ((millis() - timer) > 1000) {
timer = millis();
lcd.setCursor(3,0); // first is column, second is row
lcd.print("Angle:");
lcd.print(int(mpu.getAngleZ()));
Serial.print(", Z: ");
  Serial.print(angle[2]);
delay(1000);
}
}
```

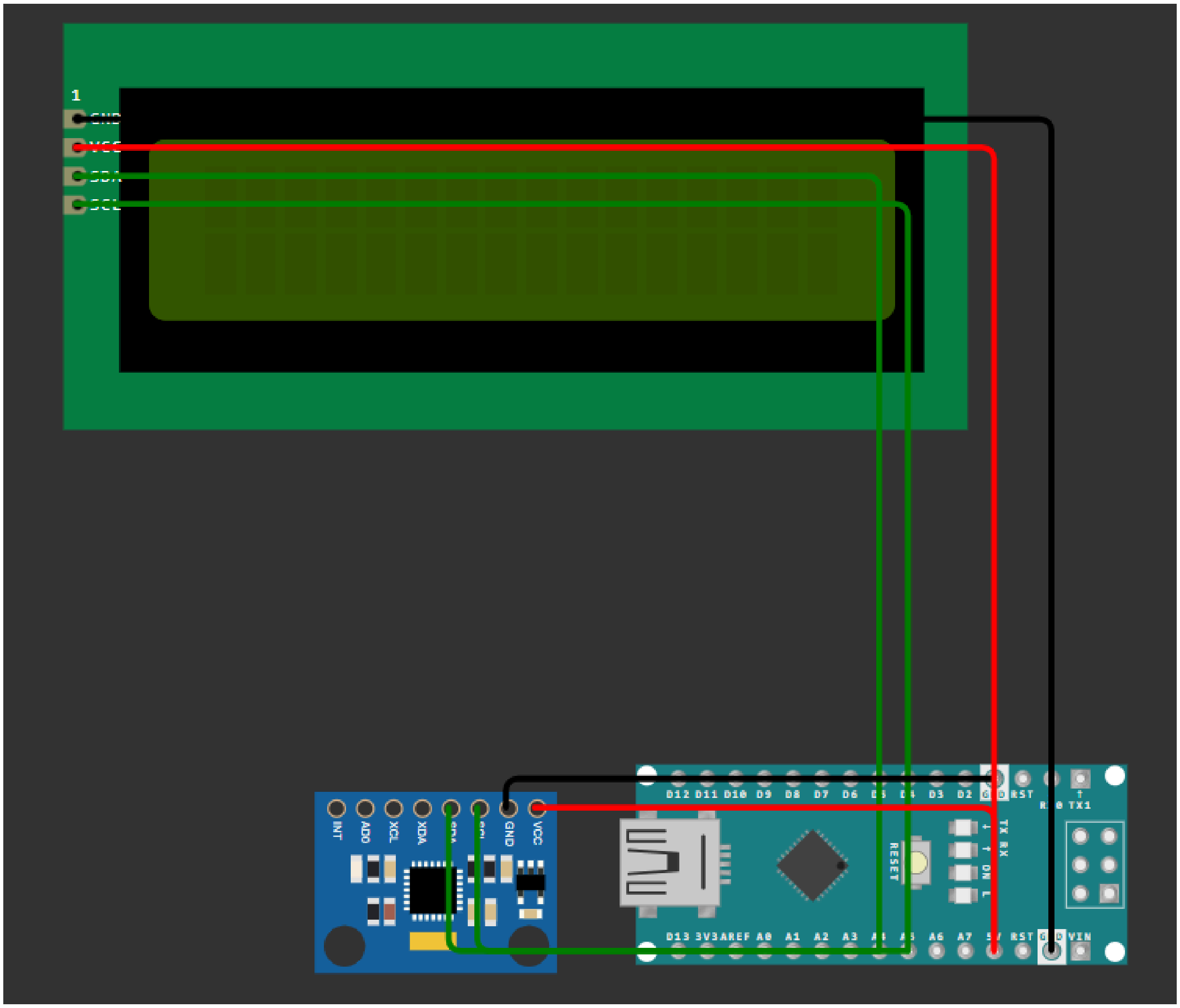
Jan. 18:

- Finished the CAD model of the device to store the circuit inside (using OnShape)
- Some dimensions may need to be changed to account for clearance and proper sizing of circuit components
- Current CAD model:



Jan. 19:

- Built circuit for device (physically and online)
    - Uses microcontroller, breadboard, male and female wires, MPU 6050, and LCD 16x2



Jan. 22:

- Decided to build the device using LEGO instead of CAD due to time constraints
- Will use CAD and 3D print it for the final iteration (this is just v1)


- Completed "data/analysis" slide
- Completed "limitations" slide
- Completed "conclusion" slide
- Completed "references" slide

Data/analysis:

Phone leveller (º)	Trial 1 (º)	Trial 2 (º)	Trial 3 (º)
-90	-88	-87	-87
-60	-59	-60	-58
-30	-29	-30	-30
0	0	0	0
30	32	30	29
60	61	59	60
90	88	87	88

- Device readings were only off by a maximum of 3 degrees
- 90 degrees had the largest difference, the device read 87 degrees
- No changes at 0 degrees

Limitations:

- The device currently only measures the tilt on the **y-axis**
- x or z axis measurements to detect body movements related to BPPV
- Still needs to be 3D printed for final iteration, for strength and stability
- There is currently no **alert system** for BPPV-associated angles
    - Using either an LED or a buzzer
- Device will need to be scaled down for real-world use
    - The prototype may be too large and heavy to be used daily

Conclusion:

The purpose of this experiment was to determine if a device using an accelerometer could accurately detect head angles. The hypothesis was supported as the device successfully measured angles ranging from -90 to 90 degrees with maximum errors of 3 degrees. These results demonstrate that the first iteration of the device can efficiently track tilt angles with minimal errors. In future iterations, an alert system for BPPV-associated angles will be added, alongside an additional axis of measurement for more precise results.

Feb. 10:

Timetable (City-Wide Science Fair):

Date	Milestones
Feb.10 - 16	• Finish detection device ○ Buzzer as an alarm ○ Possibly find a way to 3D print the case? ○ Updated experiment
Feb.16 - 23	• Upload information onto CYSF website ○ Detailed for each segment ○ Rerecord video
Feb.23 - Mar. 23	• Work on trifold ○ Should be more concise and words should be easy to read

	○ Try to include all information ○ Make the information fill the trifold
Mar.23 - Apr. 8	● Prepare for in-person presentation ○ Use cue cards ○ Practice looking at the audience and sounding engaging

- Added code for buzzer into pre-existing code
- Buzzer works, but it interferes with LCD reading
    - Will have to look into it

Feb. 14:

- LCD was not working with buzzer
- Currently using serial monitor online to see the angle, which allows for more accurate and precise values
- BPPV recurrence rates have commonly been found to be tilting your head back and looking straight down, so the buzzer activates from less than -20 degrees and greater than 70 degrees
    - It does not activate from in between -20 and 70
- On the slideshow, I have decided to include both experiments
    - Experiment 1: Testing accuracy of angle measuring on device
    - Experiment 2: Testing accuracy of buzzer on device

Feb. 16:

- Added LCD back through finding code errors
- The angle can now also be displayed in decimal format if I want more precise results

```
#include <Adafruit_Sensor.h>
#include <Wire.h>
#include <MPU6050_light.h>
#include <LiquidCrystal_I2C.h>

#define buzzerPin A0
const int triggerAngle1 = 70;
const int triggerAngle2 = -20;
bool buzzerOn = false;

MPU6050 mpu(Wire);
```

```
LiquidCrystal_I2C lcd(0x27,16, 2); // defining lcd object - 0x27 =
address, 16 = columns in lcd, 2 = rows in lcd
unsigned long timer = 0;

void setup() {

Serial.begin(115200);
Wire.begin(); // initalize connection between microcontroller and sensor
mpu.begin(); // initialize mpu (sensor)
mpu.calcOffsets(); // define original positon - will remember this as 0
degrees for code
lcd.init();
lcd.backlight();
pinMode (buzzerPin, OUTPUT);

}


void loop() {

  mpu.update();
  float angle[3] = {mpu.getAngleX(),
                    mpu.getAngleY(),
                    mpu.getAngleZ()};

  Serial.print("["); // shows on serial monitor
// Serial.print("] X: ");
// Serial.print(angle[0]);
  Serial.print(", Y: ");
  Serial.print(angle[1]);
  Serial.print(", Z: ");
  Serial.print(angle[2]);
  Serial.print("\n"); // creates new line on serial monitor
//delay(100);


if ((millis() - timer) > 1000) {
timer = millis();
```

```
lcd.setCursor(3,0); // first is column, second is row
lcd.print("Angle: ");
lcd.setCursor(3,1);
lcd.print ((int)angle[1]); // makes angle whole number - remove "int" for
decimals on lcd


bool notDanger = (angle[1] > triggerAngle2) && (angle[1] < triggerAngle1);

if (notDanger && buzzerOn){
  noTone (buzzerPin);
buzzerOn = false;
}

if(!notDanger && !buzzerOn){
  tone (buzzerPin, 500);
  buzzerOn = true;
}
}



}
```

Feb. 17:

- One of the wires that connects to the buzzer broke, which cannot be fixed

- Since I only need to make one tone with the buzzer, I can still use my active buzzer as both the active and passive buzzers will have the same role

- Updated code: Uses digitalWrite for buzzer due to change in type of buzzer

```
#define buzzerPin 12

bool notDanger = (angle[1] > triggerAngle2) && (angle[1] < triggerAngle1);

if (notDanger && buzzerOn){
  digitalWrite (buzzerPin, LOW);
  buzzerOn = false;
}

if(!notDanger && !buzzerOn){
  digitalWrite (buzzerPin, HIGH);
  buzzerOn = true;
```

Experiment (for V2 of device):

Hypothesis:

If a buzzer is used as an alarm to alert users when they reach head angles associated with BPPV, **then** the buzzer will activate at those angles and remain off at non-triggering angles, **because** it is programmed to respond to specific threshold angles linked to BPPV-related head positions.

Variables:

Independent: Angle of tilt.
Dependent: Activation of buzzer.
Controlled:
- Tested on the same surface
- Same position of buzzer on device
- Same reference tool for reference angles

Procedure:

1. Set the device at 0º on a flat surface.
2. Move the device slowly, checking the angle at either -21, -20, -19, 69, 70 or 71 degrees. Use a phone leveller to measure the angle.
3. Hold the device position for 5 seconds.
4. Record whether the buzzer was activated on a datasheet.
    a. The buzzer should activate from any angle less than or equal to -20º
    b. The buzzer should not activate from any angle between -20º and 70º
    c. The buzzer should activate from any angle greater than or equal to 70º
5. Return the device to 0º and reset it for accuracy.
6. Repeat steps 4-6 two additional times for the same angles (3 trials in total).
7. Repeat steps 3-7 for the remaining angles.

Data:

Phone leveller (º)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
-21	ON	ON	ON	ON	ON
-20	ON	ON	ON	ON	OFF
-19	OFF	OFF	ON	OFF	OFF
69	ON	OFF	OFF	ON	OFF
70	ON	OFF	ON	ON	ON
71	ON	ON	ON	ON	ON

Using this information:

a. The buzzer should activate from any angle less than or equal to -20º
b. The buzzer should not activate from any angle between -20º and 70º
c. The buzzer should activate from any angle greater than or equal to 70º

We can calculate the reliability of the buzzer:
(# of successful trials / # of trials) x 100%

Reliability (%) = (25/30) x 100% = 83%

Analysis:

- The buzzer usually activated at the correct angle
- The most inaccurate results were at -19 and 69 degrees

- Would often oscillate between the real angle and the buzzer trigger angle, which would cause the buzzer to be activated (1 degree difference)
- The most accurate results were at -21 and -71 degrees
  - Same buzzer condition regardless of the one degree angle error
- Errors may be due to shaky hands causing angle to change

Limitations (updated):

- Device will need to be scaled down for real-world use
  - The prototype may be too large and heavy to be used daily
- Buzzer sound may become irritating for potential users
  - A better solution may be more effective and comfortable

Conclusion (updated):

The purpose of this experiment was to determine if a device using an accelerometer could accurately detect head angles. The hypothesis was supported as the device successfully measured angles ranging from -90 to 90 degrees with maximum errors of 3 degrees, and an alert system using a buzzer was incorporated for BPPV-associated angles. These results demonstrate that the second iteration of the device can efficiently track tilt angles and warn potential users with minimal errors. In future iterations, a scaled-down model of the device could be implemented for user comfort.

- More slides have been added to the online presentation, outlining the second experiment

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