Wearable Light Logger for the Treatment of Mood Disorders

Final Report

Date: 12/11/2024

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Abstract

Light therapy is emerging as a potential treatment for mood disorders, more specifically Seasonal Affective Disorder. However, the amount of light necessary for complete remission of depressive symptoms is not well understood. Current devices designed for logging light intake are not tailored for clinical research, instead they are used for diagnostic purposes for myopia. In hopes of closing this gap, a wearable light logger has been developed to measure light intensity, in lux, that is reaching the retina, as requested by the client, Dr. Jean Riquelme. The device consists of a circuit with a photodiode light sensor which connects to a microprocessor to display the recorded signals in light intensity. The device was tested for both accuracy, using a light source with known intensity similar to outdoor settings, and for comfortability using a questionnaire. Accuracy testing showed that the device measured within 5% accuracy of three known illuminance values. Questionnaire data showed favorable results suggesting that the device is both comfortable and inclusive. Successful implementation of this device could advance clinical research, allowing for more effective treatment for mood disorders, and improving remission rates for patients.

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Introduction

Impact and Motivation

Mood disorders constitute a category of psychiatric conditions characterized by disturbances in an individual's emotional state. Research indicates that approximately 21.4% of adults will experience a mood disorder at some point during their lifetime [1], with Seasonal Affective Disorder (SAD) impacting up to 16% of the population worldwide [2]. The effectiveness of first-line antidepressants is questionable, with a response rate of just 50-60% in adults, while only 35-40% experience remission symptoms [2]. Additional treatment apart from medication is necessary to increase response rates and remission. Analysis has revealed that a significant reduction in depression symptom severity was associated with bright light treatment and dawn simulation in SAD and with bright light treatment in nonseasonal depression [3]. Full-spectrum bright light therapy (BLT) has shown efficacy in treating mood disorders, especially SAD. However, patient response studies are lacking. Patient response studies are crucial in determining the exact treatment of mood disorders, as factors like exact light intensity and time of exposure should be determined for the most remission of symptoms. Research regarding ideal light intensity levels and time of exposure is needed to study the exact conditions needed to best treat disorders like SAD. With data regarding the light intensity that best reduces symptoms of SAD, more concise prescriptions can be made for patients with SAD or similar mood disorders. Thus, a measurement device is warranted to characterize which conditions result in the most remission of symptoms of mood disorders. A wearable light logger would provide convenient research into what correct dosages for optimal patient response look like for patients suffering from mood disorders. A wearable sensor allows for an accurate representation of light intensities that reach the retina, the presumed site of action.

Existing Designs

There are currently no wearable light logging devices meant for clinical research on the market. There are a few similar competitive products that track and record light exposure through the retina. One of the most popular products is the Clouclip [4]. The Clouclip is a clip-on sensor that attaches to a standard pair of glasses. The device performs and collects long-term real-time data and monitoring. The Clouclip is currently marketed toward children for myopia-related behavior control. The device records reading distance, reading duration, outdoor sunshine duration, and illuminance in lux. The design is not meant for clinical research use, and main user complaints include the device moving during the day because of the weight of the electronics landing on one side of the glasses frames. The sensor is not centered between the retinas, which may not accurately represent the amount of light reaching both retinas, as this project aims to record. The Clouclip does not precisely have the same function as a wearable light logger would, but it records illuminance in lux which is the main component of the wearable light logger this project aims to fabricate.

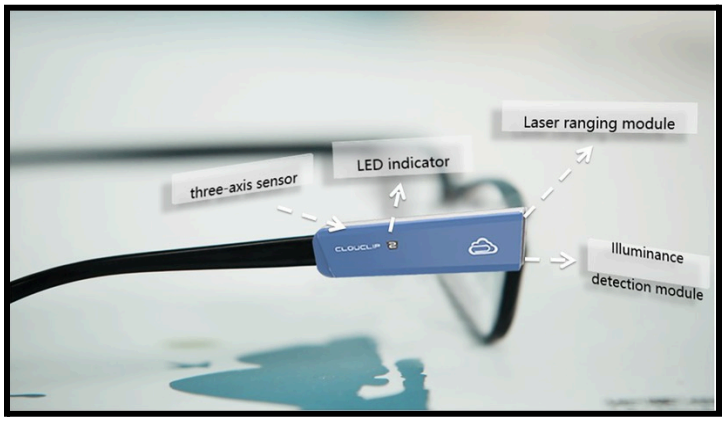


Figure 1: The Clouclip and its features [5].

Problem Statement

There are currently no clinical research devices that measure light intensity which reaches the retina. Consequently, patient responses to BLT are unknown, and more research needs to be conducted to completely understand the effects of BLT. To provide more insight into what effective treatment of mood disorders like SAD looks like, a wearable sensor that records data of light intensities entering a patient's eyes during research is necessary. By knowing the levels of illuminance that best result in remission of symptoms of SAD and similar mood disorders, more effective treatment can be prescribed by professionals resulting in a decrease in patients who suffer from mood disorders. The device must be wearable during research trials, record light intensity in lux which reaches the retina, and display the data collected in an easy-to-operate system, allowing researchers to make conclusions about the most effective treatment for mood disorders.

Background

Relevant Biology and Physiology

Mood disorders, also called affective disorders, can be divided into two categories: depressive disorders and bipolar disorders [6]. Mood disorders can be best described as prevalent occurrences of emotional disturbances. These disturbances impact negatively an individual's quality of life and increase the risk of suicide [6]. Depressive disorders are characterized by feelings of depression including a down mood, irritability, and a feeling of sadness or emptiness. Bipolar disorders are characterized by alternating mood episodes of depression and mania. Diagnosis of a mood disorder comes from a clinical evaluation by a psychiatrist who will look at past mood episodes, general medical history, and family medical history [6]. To treat depressive disorders, typically selective serotonin reuptake inhibitors (SSRIs) and serotonin-norepinephrine reuptake inhibitors (SNRIs) are the first recommendations. Depending on the evaluation of the patient, other types of medication can also be prescribed. Psychotherapy strategies such as cognitive behavioral therapy (CBT), interpersonal therapy, and behavioral activation, can also be used in combination with medication [6]. Bipolar disorders have a wide range of potential treatment options. A variety of medications can be used depending on many personal factors of the patient some examples being lithium, divalproex sodium, and antipsychotics. Other treatment methods such as CBT, several forms of therapy, and peer programs can be used in combination with medication [6]. Seasonal Affective Disorder (SAD) is a type of depressive disorder. SAD has many of the same symptoms as general depression however symptoms usually coincide with seasonal patterns. SAD typically occurs in individuals in the fall and winter months [7]. Approximately 5% of the U.S. population is affected by Seasonal Affective Disorder (SAD) annually, with symptoms occurring for nearly 40% of the year [7]. SAD is caused by several factors, mainly a result of a disruption in a person's circadian rhythm due to shorter daylight hours in the winter months. Diagnosing SAD requires an evaluation using clinical methods and tools [7]. When light passes through the eye, there are several different functions that pertain to each part of the eye. Light first passes through the cornea, then the pupil, then the lens, and once it reaches the retina, it triggers electrical signals in the brain. When light hits the retina, special cells called photoreceptors turn the light into electrical signals. These signals travel from the retina through the optic nerve to the brain [8]. Once these electric signals reach the brain, the brain is signaled to produce serotonin, a neurotransmitter that can improve mood, energy, and focus [9]. It has been hypothesized that bright light therapy may function by either correcting the winter circadian rhythm phase delay or by increasing synaptic serotonin, possibly in the serotonin-rich midbrain [9]. Many systems are under circadian control, including sleep-wake behavior, hormone secretion, cellular function, and gene expression. Circadian disruption is associated with an increasing incidence of certain cancers, metabolic dysfunction, and mood disorders, including SAD [10].

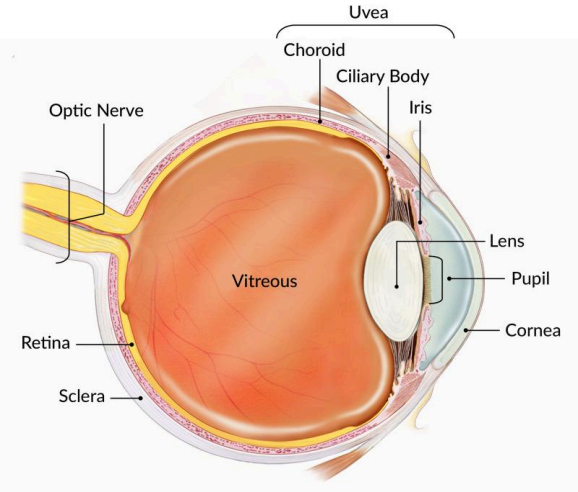


Figure 2: Anatomy of the eye [8]

Client Information

The client, Dr. Jean Riquelme, is a clinical professor at the University of Wisconsin-Madison's Department of Family Medicine and Community Health.

Design Specifications

The client has requested one functioning device that measures and records the light intensity in lux near the retina from a light therapy source used to treat mood disorders. The device should be comfortable for the user and be able to function for at least two hours at a time to allow adequate data collection. The electrical components must ensure operation on a low voltage to avoid hazardous conditions for the user. The open circuit should be operated on less than 6 volts to comply with UL 60601-1 [11]. The data recorded must be within a 5% range of the correct lux reaching the device to ensure accurate data collection. The device should weigh less than 300 g to ensure patient comfort. The device must be fabricated, and tested within the client's budget of $500.

Preliminary Designs

A. Glasses with Built-in Sensor

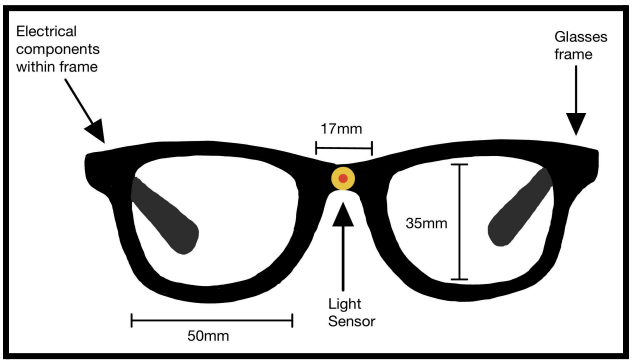


Figure 3: Glasses with Built-in Sensor

The Glasses with the Built-In Sensor design features a photoresistor sensor attached in the middle of the bridge of the glasses frame. The electronic components of the design would be integrated into the frame of the glasses by cutting out a small subsection of the frame and implementing the circuitry. The electronic components would require an integrated circuit to fit within the frame and would be completely enclosed by the glasses frame for a cohesive design. The photoresistor attached to the center of the bridge of the glasses would be able to accurately sense the light reaching the retina.

B. Glasses with Clip-On Sensor

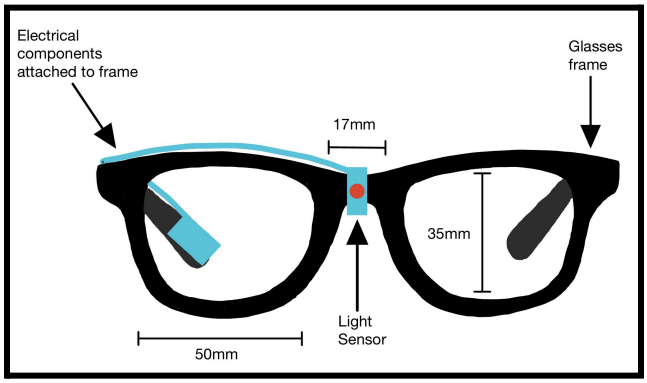


Figure 4: Glasses with Clip-On Sensor

The Glasses with the Clip-On Sensor design features a clip-on photoresistor sensor that would attach to the middle of the bridge of the glasses and clip-on electrical components attached to the frame of the glasses. The photoresistor clipped onto the glasses would be able to replicate the light reaching the retina. This design would be able to attach to any standard pair of glasses and could be removed and reattached. The electronic components attached to the frame of the glasses would feature an integrated circuit covered in a 3D-printed box that can clip onto the side of the frame of the glasses.

C. Headlamp

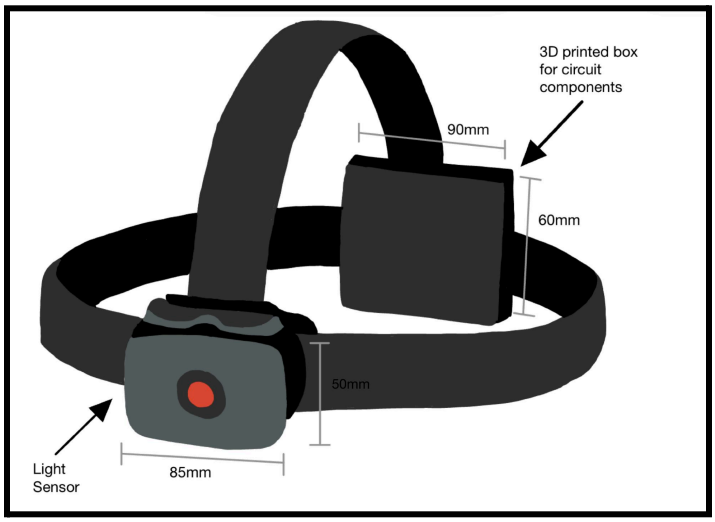


Figure 5: Headlamp

The Headlamp design features several different components. The light from the original headlamp would be removed and the photoresistor sensor would be attached to the tilting plate of the headlamp. The electronic components would be attached to the anterior of the headlamp by being positioned into a 3D-printed box that would be attached to the back strap. The electronic components would feature a breadboard circuit, Raspberry Pi, and a battery to power the circuit. The tilting aspect of the headlamp with the sensor would be able to accurately replicate the light reaching the retina.

Preliminary Design Evaluation

Design Matrix

Table 1: Design Matrix

Criteria:	**Design 1:** Glasses with built-in Sensor 		**Design 2:** Glasses with clip-on Sensor 		**Design 3:** Headlamp Design 	
Usability (20)	*3/5*	12	*2/5*	8	5/5	20
Accuracy (20)	*5/5*	20	*4/5*	16	3/5	12
Durability (20)	*2/5*	8	*1/5*	4	4/5	16
Ease of Fabrication (15)	*1/5*	3	*3/5*	9	3/5	9
Safety (10)	*5/5*	10	*2/5*	4	3/5	6
Cost (10)	*1/5*	2	*3/5*	6	3/5	6
Total: 100	**55**		**47**		**69**	

Usability:

Usability refers to the ease of data collection for the clinician, the comfort level of the patient during data collection, and the inclusivity of the design. Usability was ranked highly due to the client's emphasis on these components of the design. The headlamp design scored the highest due to its inclusive design, which allows the device to adjust to any patient's head size, and its comfortable design which easily fits over one's head. The two glasses designs require the patient to be able to wear glasses despite potential deformities a patient may have, and are not adjustable making the two designs less comfortable and inclusive than the headlamp design. Additionally, the glasses with clip-on sensor design place the

electronics on one side of the glasses frames, which could tilt the glasses to one side or cause the glasses to fall off of the face during data collection.

Accuracy:

Accuracy refers to the device's ability to record data which correctly represents the intensity of light entering the eyes. The sensor should be placed between the eyes on the bridge of the nose to best represent the light reaching the retinas. The glasses with a built-in sensor scored the highest in accuracy since the sensor is placed directly on the client's desired site of action, the bridge of the nose. The glasses with a clip-on sensor scored just below the first design since the clip could potentially fall off or change angles during data collection and slightly skew the data. The headlamp scored the lowest in accuracy since the design places the sensor just above the desired site of action.

Durability:

Durability accounts for the device's necessary time of use, ease of electronic component maintenance, and the fact that the entire device should be reusable for multiple trials without replacement. The headlamp design scored highest in durability since it has easy access to the electronic components via the circuit box at the posterior of the patient's head. The electronic components could be easily replaced if needed with no destruction to the other components of the design. The two glasses designs would require more difficult replacement of electronic components, and have a more fragile design which could break more easily than the headlamp design. The glasses with clip-on sensor design scored lowest since the clip could fall off of the frames and the wire connecting the sensor to the other electronic components would be difficult to keep intact during the movement of the device.

Ease of Fabrication:

Ease of fabrication focuses on the time constraint of one semester and the available resources the team has access to, so it was rated slightly lower than the previous three criteria since the team has access to a sufficient amount of resources. The designs scored similarly in this category with the glasses with built-in sensor scoring lower than the other two designs. This is mainly due to the need for hollow glasses frames which would require more time to fabricate, and incorporating the electronics into the small hollows of the frames which would be difficult. The other two designs have fairly similar designs regarding how the electronics are fabricated on the exterior and would be about the same amount of difficulty to fabricate.

Safety:

Safety should be considered when designing the prototype. However, the device will be used in a controlled research setting and presumably treated with great care as a research tool, so safety is ranked lower than the previous criteria. The glasses with built-in sensor design scored highest since all electronics are internal and pose the least risk of shocking the patient. The other two designs have electronic components that are less internally contained and could pose a hazard to the user if the device is not handled carefully.

Cost:

Cost is ranked low on the matrix since our budget of $500 should cover the costs for all of our design. The only significant difference in cost may be the size differentiation of electronic components, with smaller components costing more than the components already on hand from Sparkfun kits. The glasses with a built-in sensor would need the smallest components, so it scored the lowest in the cost category.

Proposed Final Design

Based on the criteria above, the proposed final design was design C: Headlamp, which would undergo slight modifications through the fabrication process. The choice was made due to its high score in the usability and durability categories of the design matrix. Design C can be simply fabricated to be adjustable to any patient's needs and features padding to

maximize the patient's comfort. The circuit box allows for easy maintenance and cleaning. The accuracy of the headlamp design will be improved by allowing the sensor to sit lower on the forehead, closer to the bridge of the nose. The electronic components will be comprised of a circuit board containing a Wheatstone bridge with a piezoresistive sensor incorporated to measure light intensity in lux, which will feed into two comparators to reduce noise and lower output impedance, then pass the signals through a differential amplifier to amplify the signal before sending the signal to a raspberry pi system-on-a-chip (SOC) which will be programmed to convert the sensed voltage into light intensity and display the values for easy interpretation by the researcher. The proposed design will be powered by a CR2450 coin battery, allowing the device to be wireless. A circuit diagram is included below, with R4 as a photoresistor.

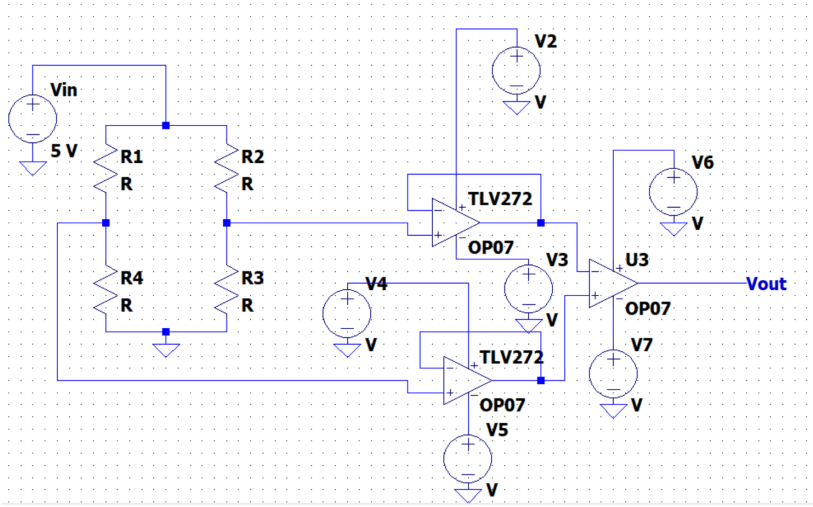


Figure 6: LTSpice circuit schematic of a photoresistor instrumentation (R4 as a photoresistor)

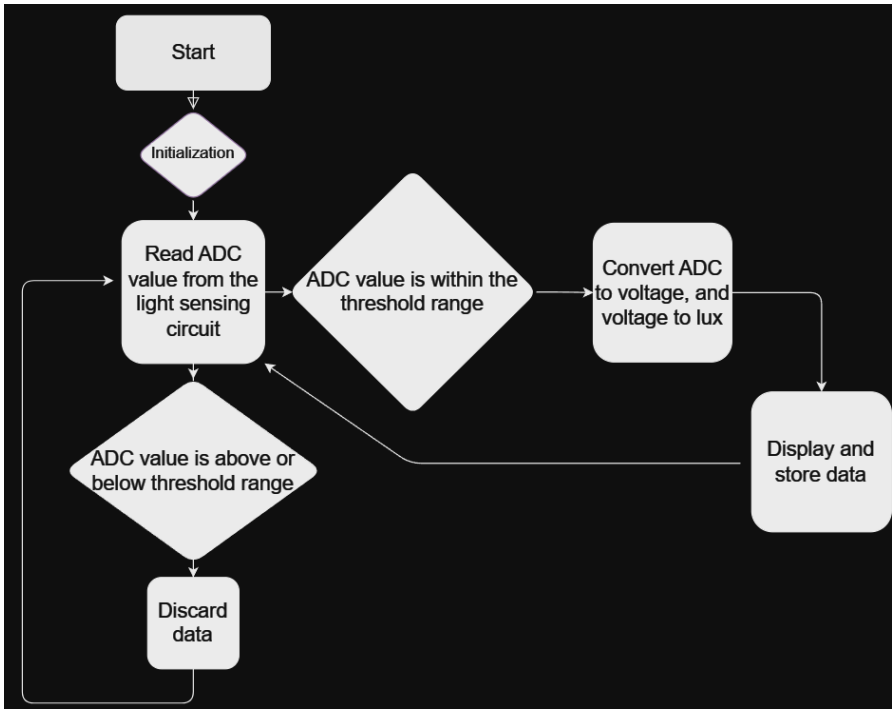


Figure 7: Block diagram of the light sensor system

Fabrication

Materials

The final design features a more simple material composition than the proposed final design. The headlamp features elastic straps surrounding the circumference as well as over the top of the patient's head to ensure no movement occurs during testing to ensure accurate readings are being taken at the presumed site of action. Instead of using a battery to power the device, the device plugs into a monitor which the researcher may use to display sensor readings and power the Raspberry Pi SOC. This modification simplifies the electronics, and reduces the amount of components needed, providing more accurate readings than the proposed final design would have. The device will only be used in clinical research settings where the patient is stationary, so there is no need for wireless connections, and the accuracy of the design should be prioritized instead. The electronic portion was changed to feature one breadboard with a potentiometer, a photodiode sensor, and a Raspberry Pi Pico W. The potentiometer changes the amount of resistance to the 3.3 V power supplied, and the sensor changes current output and therefore voltage output with changing light intensities it senses. One circuit box 3D printed using lightweight PLA will encase the electronics and will contain a slide-on lid with a hole for the sensor to poke through, as well as a hole in the side of the box for the micro USB to plug into the Raspberry Pi. The circuit box will be attached to the headlamp via hook and loop fasteners that will be adhered to both the box and the plastic part of the headlamp. This feature allows for easy disinfection between research trials, so the straps can be washed without damaging the electronic components, and increases safety by reducing the risk of spreading bacteria from one patient to the next, and of electrocution during cleaning. Refer to Appendix B for details of the materials purchased to fabricate the device.

Methods

The circuitry was constructed by attaching the potentiometer and Raspberry Pico to the breadboard. The photodiode sensor was soldered to two headers and then connected to the potentiometer and Raspberry Pico using wires. The computer powered the Raspberry Pi Pico W, which powered the potentiometer. By adjusting the potentiometer to an ideal position that amplified the change in voltage produced by the sensor, the most accurate values could be displayed. The sensor was soldered onto two longer wires as seen in figure 10 so it could extrude through the hole in the circuit box. The sensor was connected to the potentiometer with the correct polarity to ensure accurate readings. The box containing the circuitry was 3D printed and two holes were made in the box by drilling, chiseling, and filing. The circuitry was inserted inside the box with the sensor protruding out the hole on the lid of the box. The sensor was secured with tape to ensure no movement during testing. The headlamp originally purchased was altered by removing the light portion and filing down the remaining components for a flat surface on the front plate. Hook and loop connectors were attached to the back of the box and the front plate of the headlamp. The headlamp and circuit box were then secured and the Raspberry Pi was connected to the laptop via a micro USB cable. The code was created using a calibration curve to take the input voltage and convert it into illuminance, then display it on the serial monitor. To create the calibration curve, average voltages were recorded at three known light intensities and then connected with an exponential line of fit in Excel. To calibrate the device, the HappyLight by Verilux was used, which emits known light intensity values of 5000 lux, 7500 lux, and 10000 lux, and is often used in BLT [12]. Refer to Appendix C for a detailed fabrication protocol.

Final Prototype

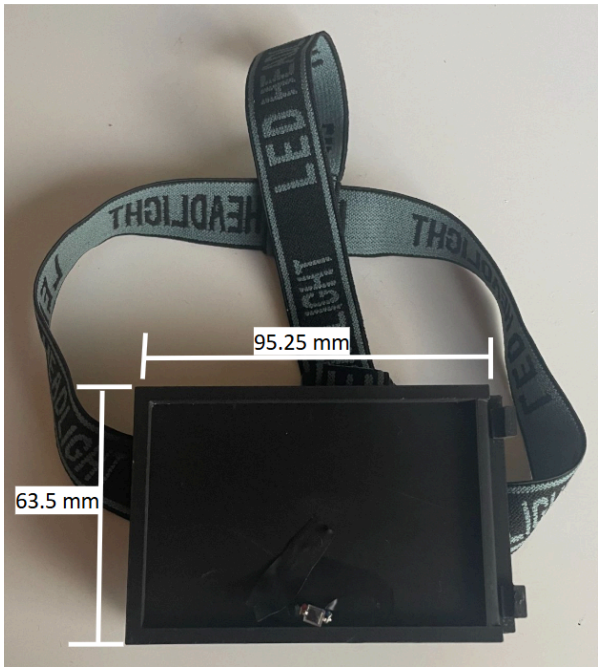
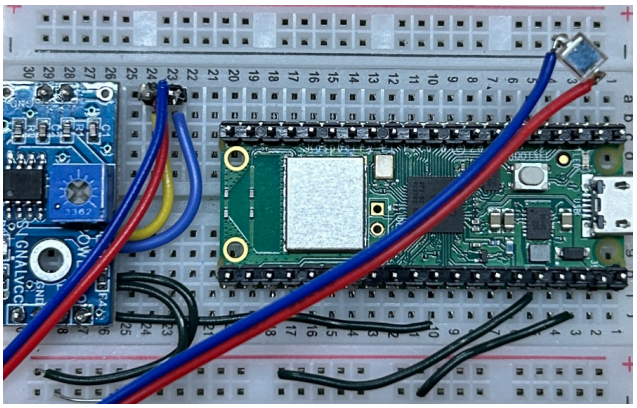


Figure 8: Final light logger design featuring the sensor near the bottom of the circuit box, and adjustable elastic head straps

Figure 9: Final light logger design featuring the depth of the box and hole for the microcontroller connection to monitor



```python
from machine import ADC, Pin
import time
import math

adc = ADC(Pin(26))

def read_voltage_u16():
    adc_value = adc.read_u16()
    adc_real = 65535 - adc_value
    voltage = (adc_real / 65535) * 3.3
    return voltage

def calculate_lux(voltage):
    if voltage <= 0:
        raise ValueError("0 lux")

    lux = (math.log(voltage / 0.0702)) / 0.000162
    return lux

while True:
    voltage = read_voltage_u16()
    try:
        lux = calculate_lux(voltage)
        print("Illuminance: {:.2f} lux".format(lux))
    except ValueError as e:
        print("Error computing lux:", e)
    time.sleep(0.5)
```

Figure 10: Final circuit (left) featuring a potentiometer, photodiode, Raspberry Pi pico W, and the final code (right) using MicroPython

Testing and Results

Accuracy Test

The accuracy test was performed to see how accurate the sensor's readings were, aiming to obtain percent variance from the incoming light source's known illuminance. The light logger was worn with the sensor on the bridge of the wearer's nose. A HappyLight, a light source commonly used for BLT, was placed 30.5 cm away from the sensor, replicating the conditions of a typical BLT session [9]**.** The HappyLight was turned on at 5000 lux, 7500 lux, then 10000 lux for one minute each. The output intensity values were recorded at each HappyLight intensity value, and compared using standard error bars to create variance values of the trials. This process was repeated in a dark room and in a room with ambient light.

The results from the accuracy test yielded less than 5% error for both trials. As shown in figure 11, the trial conducted in a dark room yielded an error of 2.77% at 5000 lux, 3.79% at 7500 lux, and 1.34% at 10,000 lux.

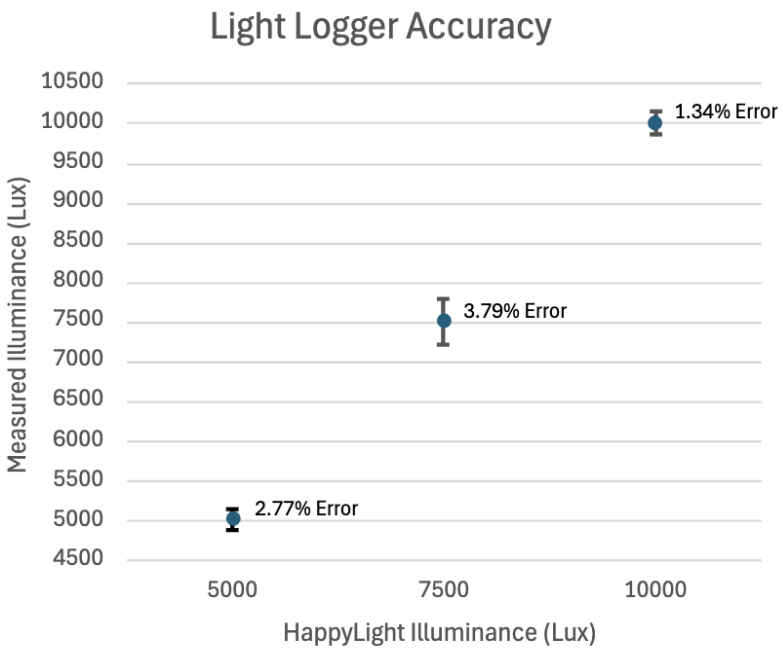


Figure 11: Light logger percent error at three known illuminance values.

Comfortability Test

To assess the compliance of the device according to client criteria —specifically regarding comfort, time of use, and design inclusivity—a survey was conducted using Google Forms. The survey contained the following questions:

- Is the device comfortable? (rated on a scale of 1-5)
- Does the device fit your head?
- Is the device weight comfortable?
- Would you feel comfortable wearing this device for 2 hours?

After having participants wear the device for several minutes, 38 survey responses were recorded, with generally favorable results. All responses (100%) indicated that the design was comfortable enough to be worn for two-hour intervals, the maximum time of use suggested by the client, shown in figure 14. Comfort ratings were also positive with 63.2% rating the device 5 out of 5 and 34.2% assigning a 4 out of 5, shown in figure 12. Additionally, 100% of participants stated that the device fits their heads properly and that the weight of the device was comfortable.

These results show that the design successfully met all of the client's evaluated criteria. The positive feedback suggests that the design will be successful in its intended use, in terms of wearability and comfortability.

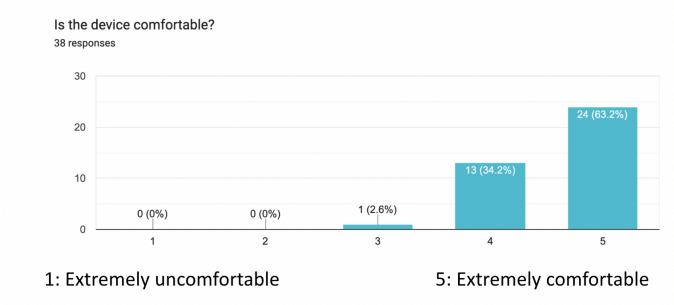


Figure 12: Survey responses to: "Is the device comfortable?"

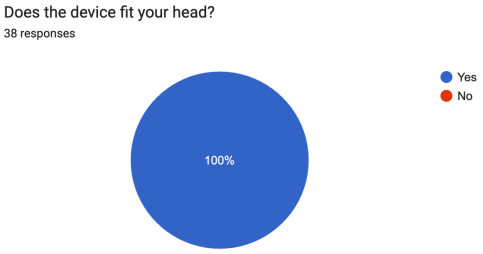


Figure 13: Survey responses to: "Does the device fit your head?"

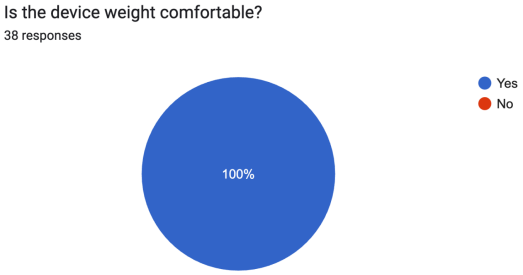


Figure 14: Survey responses to: "Is the device weight comfortable?"

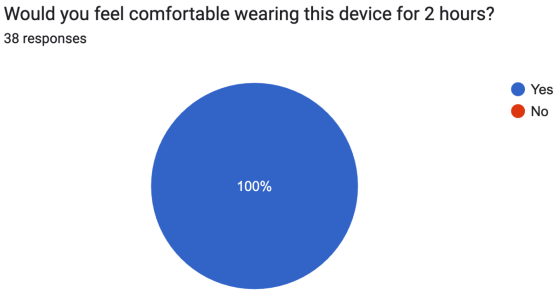


Figure 15: Survey responses to: "Would you feel comfortable wearing this device for 2 hours?"

Discussion

The results gathered by testing confirm the design's compliance with the client's criteria of weight, cost, comfort, safety, inclusivity, time of use, function, and accuracy. The final design weighed 138.07 g and cost $84.81. The device was tested similarly to the existing protocols for bright light therapy and ran for three hours at a time [9]. The survey results provide confidence that a wide range of patients could use this device, as a random, diverse, and relatively large (n=38) population was sampled. These results support the integrity of the design for use in a clinical research setting.

As a result of the device meeting all the criteria set by the client and by previous research, no changes need to be made to the device itself after evaluation. Instead, a change to the testing procedure could be made. Because the device's accuracy was tested using the same light source to which it was calibrated, the integrity of the testing is questionable. To provide more convincing accuracy testing, the same procedure should be done using an alternate light source with known light intensity settings that differ from or are more varied than the HappyLight's settings. This alternative light source should emit light within the range of illuminance used in BLT to ensure the device functions as it is meant to in a research setting.

Some sources of error in accuracy and reductions in the level of comfort of the device were due to the bulkiness, size, and weight of the circuit box. To improve these categories, the circuit should be made smaller, so that the sensor lies closer to the bridge of the nose than it does now. The current circuit box is 28.58 mm deep. Reducing this depth to make the sensor sit closer to the bridge of the nose would provide a more accurate measurement of light reaching the patient's eyes, and improve comfort by reducing the weight and size.

Conclusions

The Wearable Light Logger was created to allow clinical researchers to document light intensity reaching the patient's eye during clinical research. In doing so, researchers can identify the relationship between bright light therapy and seasonal affective disorder (SAD) and determine the treatments that achieve the highest symptom remission. The device's final design contains a photodiode sensor that converts input light intensity into voltage readings, which are processed by a Raspberry Pi Pico W to output luminous intensity in lux. The device is able to accurately measure light intensity from 5000 to 10000 lux within a 5% tolerance range in both dark and ambient light conditions. During testing and calibration, one flaw was identified; the device was never checked for accuracy with different known light sources and was instead calibrated and tested to one measurable light source. In the future, the light logger should be tested against known light intensities from multiple sources to ensure accuracy. The device should also have a PCB instead of a solderless breadboard, the ability to export and print data to a website, and a battery rather than a wired connection. These features would allow the wearable light logger to be more convenient for researchers to use, and present the opportunity for at-home use.

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Appendix A: PDS

Wearable Light Logger to Facilitate Full Spectrum Light Dosing for Mood Disorders

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Lab 304

September 19, 2024

Function:

Mood disorders are a category of mental illnesses in which the underlying problem primarily affects a person's emotional state. An estimated 21.4% of adults experience any mood disorder at some point in their life [1], with Seasonal Affective Disorder impacting up to 16% of the general population worldwide [2]. With only 50-60% of adults responding to first-line antidepressants, and 35-40% experiencing remission symptoms[2], additional treatment is needed. Analysis has revealed that a significant reduction in depression symptom severity was associated with bright light treatment and dawn simulation in seasonal affective disorder and with bright light treatment in nonseasonal depression [3]. Full-spectrum light therapy has been proven to be successful in treating mood disorders, especially seasonal affective disorder, but patient response studies are lacking. There are currently no wearable light logging devices meant for clinical research on the market. A wearable sensor allows for accurate representation of light intensities that reach the retina, the presumed site of action. A wearable light logger would provide convenient research into what correct dosages for optimal patient response look like for patients suffering from mood disorders.

Client requirements:

- Functional wearable device that can record the amount of illuminance in lux near the retina
- The device must be able to be used up to once a day for a maximum period of 2 hours
- Must be comfortable and wearable for the user
- Must accurately interpret the lux the device is intaking
- Budget must be within $500

Design requirements

1. **Physical and Operational Characteristics**
    a. *Performance requirements* **-** The device should be able to accurately measure and record the amount of light measured in lux received from a light therapy source used for mood disorders. The device must be wearable on the user and comfortable to avoid discomfort and strain. The device must be able to be used up to once a day for a maximum time of 2 hours. The device must be able to be used multiple days in a row and be able to be put on and removed easily by the user.

    b. *Safety* - The device must be used in the parameters of safety outlined with exposure to light therapy. The device must not be used more than once a day for a maximum time of 2 hours to reduce light therapy harm to the user. The device must be lightweight on the user to not cause harm to the user's eyes. All attachments on the device must be securely connected to avoid breakage and sharp edges. The electrical components connected to the device must be properly concealed for use on the body of the user. For electrical components, the device should ensure operation on a low voltage to minimize the risk of electric shock. The device must adhere to

relevant safety standards for machinery safety and risk management in medical devices. Clear user instructions should be given to the user to ensure safe and effective use.

c. *Accuracy and Reliability* - The device should be able to properly sense and record the amount of light recorded in lux coming through its sensor. The device must accurately record the lux data daily upon use, for up to multiple days in a row. The data recorded must be within a 5% range of the correct lux amount implemented upon the device from the light used.

d. *Life in Service* - The device should be able to be used periodically based on the user's needs. The device must be able to withstand use once a day or less. The device should be able to be on and in use for a range of 15 minutes - 2 hours based on the user's needs and personal preferences.

e. *Shelf Life* - As our device's intended use is based on clinical testing, the device is intended to have an extended shelf life and/or rechargeable batteries such that our client and others have ease of operation. While in storage, we intend for the device to be turned off and stored at room temperature to preserve the integrity of the sensors, wiring, and chips. We intend to avoid leaving the device on to stop chip overload and to protect battery life.

f. *Operating Environment* - The device is intended to be used in a clinic, and will be mainly indoors. It's operation will take place at 70℉ or 20℃(±5°), and a standard pressure of 1 atmospheres. While the part specifications haven't been decided yet, we intend to have the

device stored in a dry and dust-free environment to preserve the device's functionality. The material of the device hasn't been chosen, however, we intend to make it durable such that a tester or testee could use it without an abundance of caution.

g. *Ergonomics* - The device should be functional for ages 18+. Due to the undetermined measurements of the device, we are unable to provide exact numbers or a hyper-specific target audience. However, the device is intended to be used on adults in a clinical testing setting, so clinicians will be able to properly instruct patients on safe and careful handling procedures. The exact method of logging light has not yet been determined - once this occurs, other ergonomic factors will be addressed.

h. *Size* - The device has not been prototyped yet, so we are unable to provide exact size specifications, portability details, and space availability. We intend for the device to be wearable, inconspicuous, and convenient to clinical patients. While there isn't a maximum size, the device will require patients to be at least 18+ or have similar features to an adult to fit properly. As we have not decided on the technological specifications for the device, it is impossible to assess the device's accessibility to maintenance.

i. *Weight* - The device needs to be fairly lightweight although specific requirements have not yet been determined. The optimal weight will vary based on the ultimate design chosen, however, in each case, it needs to be assured that the weight of the device will be comfortable for the user, and will not cause them any harm.

j. *Materials* - The device is proposed to be in contact with the skin so metal should be avoided in order to make sure that there is no skin irritation caused by the device. Using materials such as plastic, or elastic will be acceptable as long as they do not cause irritation or cause the device to be uncomfortable to wear.

k. *Aesthetics, Appearance, and Finish* - There are no requirements in terms of visual aesthetics and appearance. Because the device will be used for clinical purposes as opposed to commercial use, appearance is not a critical factor in its design.

2. **Production Characteristics**
   a. *Quantity:* One device will be needed for research. The device should be reproducible for other researchers.

   b. *Target Product Cost:* The target cost for this product is a budget of $500.

3. **Miscellaneous**
   a. *Standards and Specifications* - US6737629B2[4] presents a patent for a standard light sensor which is used in the rearview mirrors of cars. This patent details some internal components of a light sensor that may be useful in designing our prototype.

b. *Customer* - Our client, Dr. Jean Riquelme, is a clinical professor in the Department of Family Medicine and Community Health at the University of Wisconsin School of Medicine and Public Health. She requests that our device is non-obstructive to users. Her idea includes a lightweight, non-metal based, and comfortable device. We have also been given flexibility over the target age range and aesthetic appeal.

c. *Patient-related concerns* - The device will need to be able to stay on the face or body appropriately without tilting to one side, or falling off. The device not being fastened appropriately could be concerning not only for patient safety, but also for the safety of the device. Additionally, if only one prototype is built for clinical use, the device will need to be sterilized between patients. A simple disinfectant wipe should suffice to appropriately clean the device between users.

d. *Competition* - There are a few similar competitive products that track and record light exposure through the retinas. One of the most popular products is called the Clouclip [5]. The Clouclip is a glasses clip that attaches to a standard pair of glasses. The device performs and collects long-term real-time data and monitoring. The Clouclip is currently marketed toward children for myopia-related behavior control. The device can record reading distance, reading duration, outdoor sunshine duration, and for the concern of our device, illuminance in lux. The Clouclip does not precisely have the same function as the wearable light logger, but records illuminance in lux and records which is the main component of the wearable light logger.

Appendix B: Expenses

Item	Description	Manufacturer	Part Number	Date	QTY	Cost Each	Total	Link
Component 1								
HappyLight	Light for testing sensor	Verilux	N/A	9/13/24	2	$49.99	$99.98	Link
Component 2								
Battery	Battery for chip	PGSONIC	CR2045	9/19/24	1	$1.15	$1.15	Link
Component 3								
Head Lamp	Light that attaches to head	Fire Supply Depot	FL8210-6SMD	9/26/24	1	$11.92	$11.92	Link
Component 4								
Raspberry Pi	Chip for coding	Raspberry Pi	Raspberry Pi Pico W	10/4/24	1	$7.20	$7.20	Link
Component 5								
Comparator	Building circuit	Texas Instruments	LM393PE4	10/4/24	2	$0.25	$0.50	Link
Component 6								
Battery Holder	Holder for coin battery	Digikey	BS-2450	10/4/24	1	$3.84	$3.84	Link
Component 7								

OPAMP	Building circuit	Digikey	AD8276ARZ	10/4/24	1	$7.37	$7.37	Link
Component 8								
IC DAC 12BIT V-Out	Building circuit	Digikey	MCP4726A0T-E/CH	10/4/24	3	$2.16	$6.48	Link
Component 9								
OPAMP	Building circuit	Texas Instruments	UA741CN	10/25/24	2	$0.25	$0.50	Link
Component 10								
Breadboard	Building circuit	Busboard Prototype Systems	BB400	10/25/24	1	$2.00	$2.00	Link
Component 11								
Sensor 550NM	Measure light values	Digikey	OPT3007YMFT	10/31/24	1	$2.79	$5.42	Link
Component 12								
Sensor Photodiode 900NM	Measure light values	Digikey	BPW34S-ND	10/31/24	1	$1.58	$4.21	Link
Component 13								
DFN to DIP SMT adapter	Allows for soldering components to breadboard	Digikey	IPC0083-ND	10/31/24	1	$4.79	$7.42	Link

Component 14								
Ribbon Cables	Flexible wire connection around head strap	Amazon	B08LPFX7QN	10/31/24	1	$10.39	$10.39	Link
Component 15								
Spandex	Flexible wire enclosure around head strap	Joann Fabrics	N/A	11/6/2024	1	$7.92	$7.92	N/A
Component 16								
Micro USB Cable	Longer cord connection from device to computer	Amazon	N/A	11/24/24	1	$7.69	$8.11	Link
TOTAL:	**$184.41**							

Appendix C: Protocols

Calibration Protocol:

1. Situate sensor 30.5 cm in front of HappyLight

2. Connect sensor to micropython code using a micro USB cable

3. Turn off the light to create a pitch-black environment and record three set values of HappyLight intensities (5000, 7500, 10000 lux) for one minute each

4. Record voltage values from the sensor at each lux setting and calculate values into an average

5. Create calibration curve using Excel with set lux values from HappyLight and average voltage values recorded from the microcontroller

6. Complete calibration equation using an exponential line of best fit:

y = 0.0702e^1.62E-04x
y is voltage, x is light intensity (lux)

7. Insert calibration equation into the code to complete calibration

Accuracy Testing Protocol:

1. Wear Wearable Light Logger on the head with the sensor near the bridge of the nose

2. Place HappyLight 30.5 cm in front of the user

3. Plug sensor into the monitor which is running the MicroPython code

4. In a dark room, turn on the three light settings of HappyLight (5000, 7500, and 10000 lux) for one minute each. Obtain sensor-recorded voltage values for each light setting

5. Repeat steps one through four in a room with ambient lighting, and record the voltage values

6. Obtain output intensity values from the code at each light intensity setting in both dark and ambient lighting, and create a standard error of the mean bars in Excel. Center the bars around the set light intensity output by the HappyLight, and display the percent variance of sensor output intensity values.

Comfortability Testing Protocol:

1. Conduct a survey on Google forms

2. Obtain responses from survey respondents after wearing the Wearable Light Logger for several minutes

3. Observe responses to the following questions:

- Is the device comfortable? (rated on a scale of 1-5)
- Does the device fit your head?
- Is the device's weight comfortable?
- Would you feel comfortable wearing this device for 2 hours?

4. After answering questions, record the responses of each survey respondent

Appendix D: Code/ Device Instructions

Wearable Light Logger Instructions:

1. Download Thonny, Python IDE for beginners
2. Plug cord into device and computer
3. Copy and paste the following code into Thonny

```
from machine import ADC, Pin
import time
import math

adc = ADC(Pin(26))

def read_voltage_u16():
    adc_value = adc.read_u16()
    adc_real = 65535 - adc_value
    voltage = (adc_real / 65535) * 3.3
    return voltage

def calculate_lux(voltage):
    if voltage <= 0:
        raise ValueError("0 lux")
    lux = (math.log(voltage / 0.0702)) / 0.000162
    if lux < 0:
        lux = 0.0
    return lux
while True:
    voltage = read_voltage_u16()
    try:
        lux = calculate_lux(voltage)
        print("Illuminance: {:.2f} lux".format(lux))
    except ValueError as e:
        print("Error computing lux:", e)
    time.sleep(0.5)
```

4. Click the tab in the bottom right corner
    a. Click Install or Update MicroPython
    b. The target volume box should be filled if the device is plugged in
    c. Under Micropython family, click RP2
    d. Under Variant, click Raspberry Pi - Pico W / Pico WH
    e. Click install
    f. Once done, the bottom rectangle that reads “Shell” should have three purple arrows: >>>, If not, redo steps 1-4e

5. Click the green play button in the top left corner to start recording data and the red stop button to end data collection
6. Once steps 1-4 have been completed, one does not need to redo them, even in the event of unplugging the device. If red text appears in the shell, redo steps 1-4