LED Neuromodulation Headband

Motivation

Trasncranial photobiomodulation (tPBM) uses infrared light to modulate the brain. The infrared light passes through the skull and reaches the prefrontal cortex. tPBM can increase cognitive function and promote a healthy brain. Previous research has shown the effect of 1064 nm light on brain oxygenation, corresponding to improved cognitive function. This technology is particularly useful for those experiencing cognitive dysfunction due to depression, ADHD, bipolar disorder, aging cognitive decline, and brain injury - but healthy individuals may also benefit as well. tPBM is typically performed using an infrared laser. The problem is that this laser is extremely expensive and inconvenient for people to actually use on a daily basis, as most people cannot afford $20k lasers and receive specialized training. This necessitates the need for a less expensive and more convenient light therapy system. More recently, it has been demonstrated in research that LEDs can also be used for tPBM, making treatment significantly cheaper and more accessible. This LED headband device is an attempt at an alternative to the laser, with the aim to increase brain oxygenation and improve cognitive function using infrared light.

Novelty

As mentioned before, LEDs have already been able to demonstrate tPBM effects. This device in particular uniquely features higher optical power output within a particular wavelength range that is unlike other existing LED devices for the purpose of transcranial photobiomodulation.
The LEDs of this headband device provide an average optical power density of around 160 mW/cm^2 at 1064 nm. Most other LED devices currently operate at lower wavelength ranges and power densities, but further investigation should be conducted to evaluate this.

1064 nm has shown to be an optical wavelength window for the brain to absorb energy of the infrared light most effectively. A higher optical power density means more light can pass through the skull and reach the brain. As a result, a device with a higher optical power output would reduce the amount of treatment time to achieve the desired radiant exposure.

As this device uses higher powered LEDs, certain design considerations have been implemented to address thermal dissipation. The device is equipped with a heatsink fan attached to the LED module, which is also believed to be unique in design for LED tPBM devices, but further investigation should be conducted to evaluate this.

LED Headband Characterization

Target Specifications:

- Optical power density: 250 mW/cm^2 *or* Radiant exposure: 120 J/cm^2
- Wavelength: 1064 nm
- Dissipate ~0.6 W of power as heat
- Maintain ambient temperature under 35 degrees C

Optical power density: 250 mW/cm^2 or Radiant exposure: 120 J/cm^2
Wavelength: 1064 nm
Specifications determined by previous research

Must be able to dissipate ~0.6 W of power as heat
LED Forward voltage = 1.5 V
LED Forward current = 0.6 A
Power (watts) = V (volts)*I (amps)
LED power = 1.5 V*0.6 A = 0.9 W (per LED)
Expected total radiated power = 750 mW (from datasheet)
Efficiency = (radiated power) / (LED power) = 0.75/0.9 = 0.83 = 83%
Total LED power = 4*0.9 = 3.6 W
Because ~83% efficient, about 83% power goes into optical power, the rest is turned into heat
Heat watts = 3.6 - (0.83*3.6) = 0.612 W
Therefore, it is expected that we must cool about 0.612 W of heat power.

Maintain ambient temperature under 35 degrees C

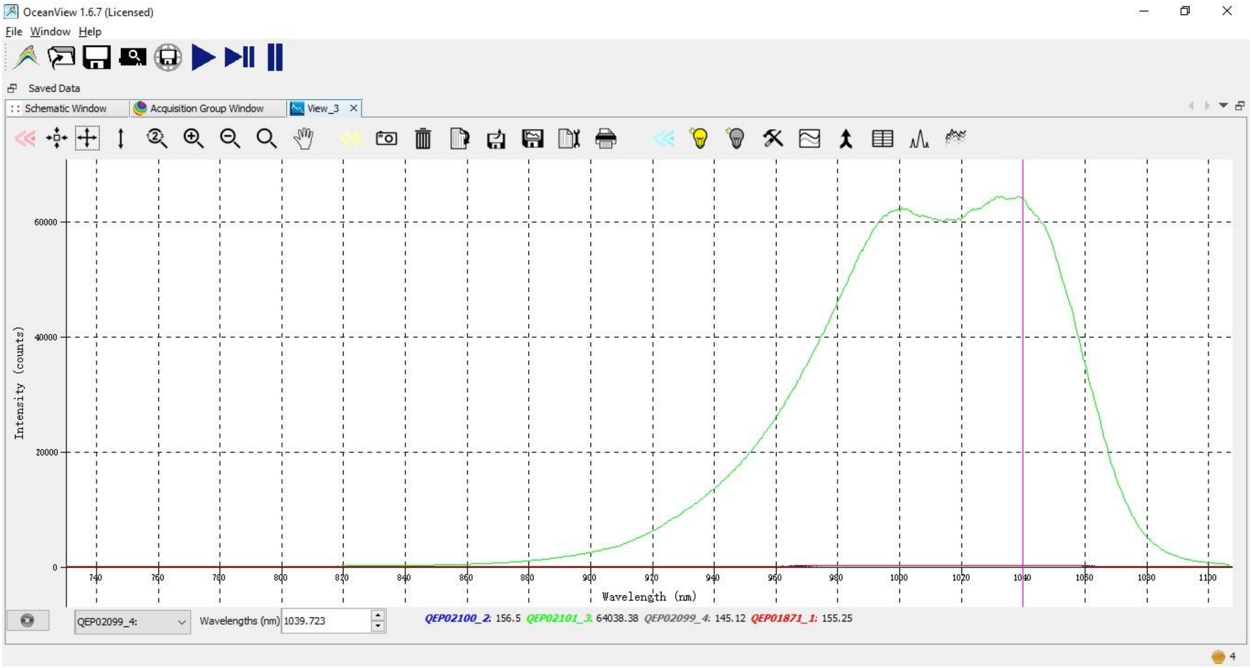
The LEDs will be in close contact with the skin and must therefore be at a safe enough temperature to use. Another reason to maintain a constant and minimal ambient temperature is because temperature affects the optical power dissipation of the LED. Higher temperatures will decrease the amount of optical power, so it is ideal to minimize ambient temperature in order to maximize optical power output.

Measurements

The following table demonstrates the power density (mW/cm^2) of the LED device at 1064 nm and board temperature over time. The power density was measured with a power meter, D1-D4 corresponding to each of the 4 LEDs on the board. The units of power density are mW/cm^2. Ambient temperature was measured using a thermistor on the board. The thermistor was monitored using an Arduino Nano microcontroller.

Wavelength: 1064 nm	Power Density D1 (mW/cm^2)	Power Density D2 (mW/cm^2)	Power Density D3 (mW/cm^2)	Power Density D4 (mW/cm^2)	Board Temp (C)	Electrical Power Output (W)
Time = 0 (min)						
1	165.3	165	160.6	161.5	24.67	3.69
4	164.3	158	154	162	24.88	3.39
8	164	158.1	151	164.1	25.12	3.69
12	159.3	161.5	158.1	159.3	25.01	3.69
16	161.2	161.3	153.1	158.7	25.2	3.69

The figure below is a measure of the light intensity corresponding to the wavelength range of the LEDs on the device. The peak was shown to be at ~1000 and ~1040 nm. The light intensity was recorded using bbNIRS.



Wavelengths (nm) 1039.723

QEP02100_2: 156.5 QEP02101_3: 64038.38 QEP02099_4: 145.12 QEP01871_1: 155.25

The following figure below is a measurement of the power density of the LEDs at the peaks 1000 and 1040 nm. The peaks were previously determined by measuring the light intensity with bbNIRS. The units for power density are mW/cm^2.

Wavelength: 1000 nm	Power Density D1	Power Density D2	Power Density D3	Power Density D4		Electrical Power Output
Time = 0						
1	96.3	102.9	96.5	102		3.69
4	97	88.5	90.5	96		3.39
8	98.3	95.5	101	100.4		3.69
12	93	97.2	96.5	98.3		3.69
16	97.4	98.6	100.3	99.6		3.69

Wavelength: 1040 nm	Power Density D1	Power Density D2	Power Density D3	Power Density D4		Electrical Power Output
Time = 0						
1	105.3	115.3	108.2	118.4		3.69
4	110	109.5	109.7	119.3		3.39
8	115.3	103.1	106.2	120.7		3.69
12	111.1	105.9	103.2	121		3.69
16	113	110.3	111.2	116		3.69

Discussion

The power density of each LED was measured to be around 160 mW/cm^2 at 1064 nm. The power density at the peaks, determined by bbNIRS, was measured to be lower than expected. The discrepancy between the light intensity measurements and the power meter measurements must be further investigated - this could either be due to the power meter or the results interpreted by the bbNIRS software. One potential reason could be due to the highly sensitive bbNIRS sensors, which can easily be over-saturated. Thus, the measurement of light intensity provided may not be reflective of the true intensity ranges. Another possibility could be the power meter itself is not measuring the peak values accurately. Therefore, these preliminary measurements should be validated with further measurements.

The power density of 250 mW/cm^2 at 1064 nm was not reached for the LED device. However, given the measured LED power density of 160 mW/cm^2 at 1064 nm, the target radiation exposure of 120 J/cm^2 can still be reached by adjusting the time of application to be 12.5 min, which is 750 seconds. This is done using a simple calculation:

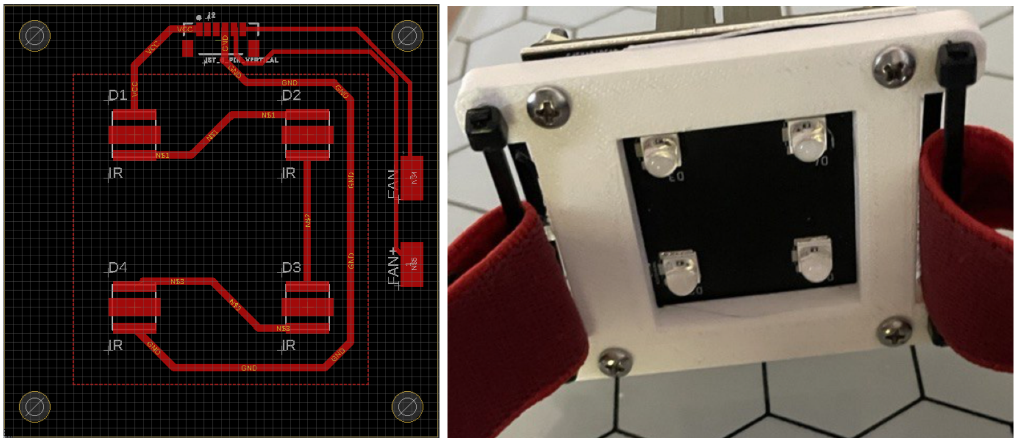
Laser: 120 J/cm^2 = 0.25 W/cm^2 * 480 seconds
LED headband: 120 J/cm^2 = 0.16 W/cm^2 * 750 seconds
Based on previous research, about 1-2% of that radiation reaches the cortical surface.
These calculations suggest that the same cortical fluence reached by the laser can be achieved by the LEDs. Tests to determine efficacy of the device must be conducted.

Device Modules

- LEDs
- Cooling unit
- Power supply
- Headband

LED PCB

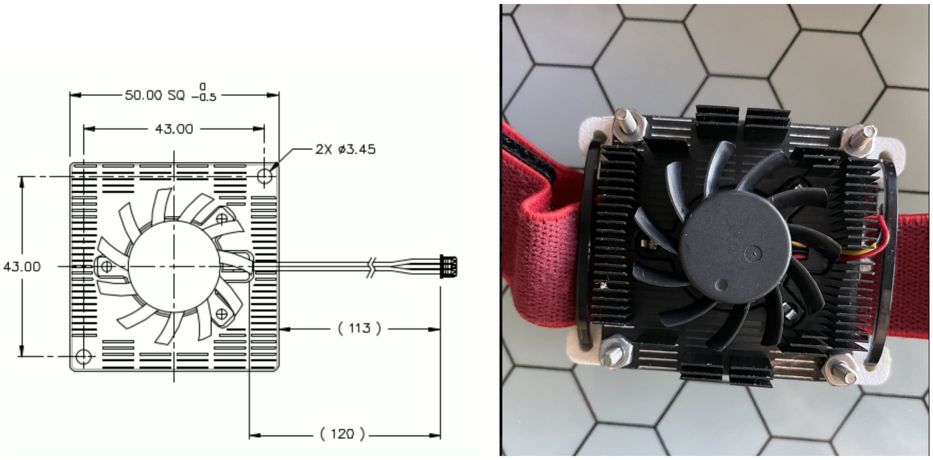
This module consists of 4 high-powered infrared LEDs (1000-1100 nm) arranged in a 2x2 cm^2 matrix on a 5x5 cm^2 printed circuit board (PCB). The LEDs will form a square on the board. The LED PCB is made from aluminum and will be mounted to a heatsink fan for effective heat dissipation. A 3D printed backplate will secure the mount of the PCB onto the heatsink fan. The initial prototype was simply connected by soldering wire to the PCB. *A more stable modification planned is to include a small JST connector that will be mounted on the PCB for secure connection to power the LEDs and fan.*



Left: LED PCB design, Right: Assembled LED PCB with 3D printed backplate.

Fan

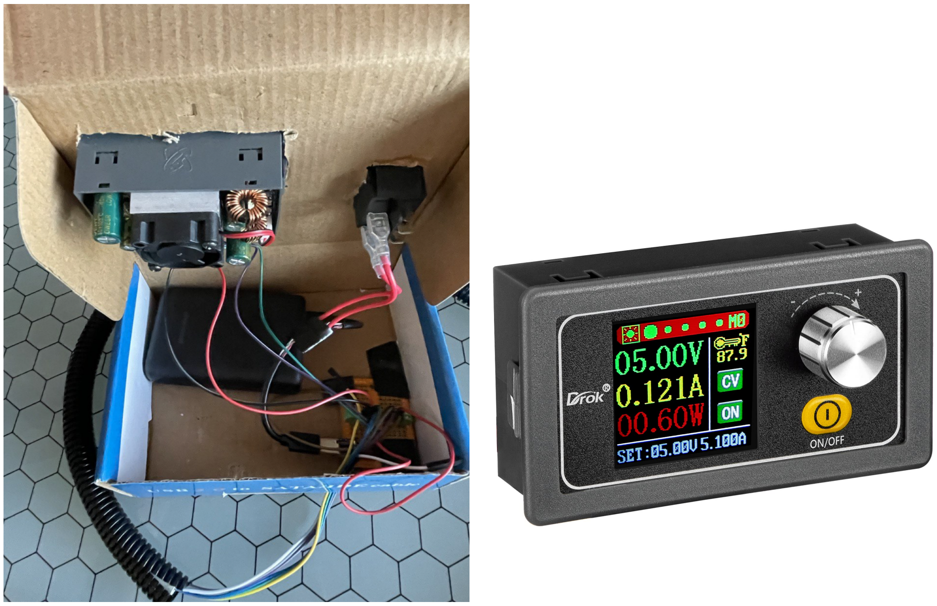
A heat sink with an integrated fan is used to dissipate the heat generated from the LEDs. The LED PCB is mounted to the heatsink fan with a thermal interface paste. The cooling unit can also maintain LED ambient temperature to be safe enough to use.



Left: Fan heat sink diagram.
Right: Fan heat sink used in the device.

Power supply and control

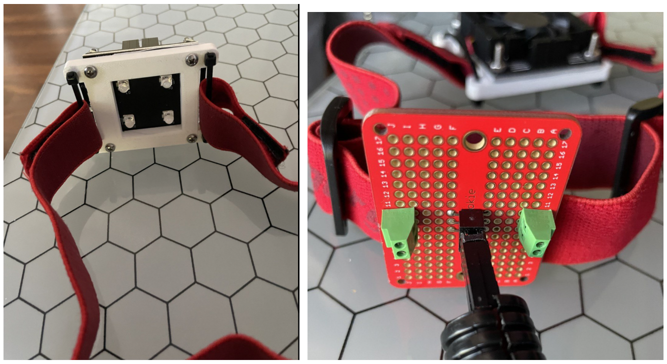
A portable battery bank (PD) supplies power to the device via USB-C. It will power an adjustable constant current driver and heat sink fan. The constant current driver will then be used to drive the LEDs at a constant current. The USB-C cable connecting the power bank to the rest of the device will be interrupted by a switch interface to provide on/off switching of the device. The figure below shows the initial prototype in a cardboard box. *The next prototype will include this circuitry in a custom laser-cut box.*



Left: Internal circuitry containing power supply, constant current driver, switch interface.
Right: Drok adjustable constant current driver used in the device.

Headband

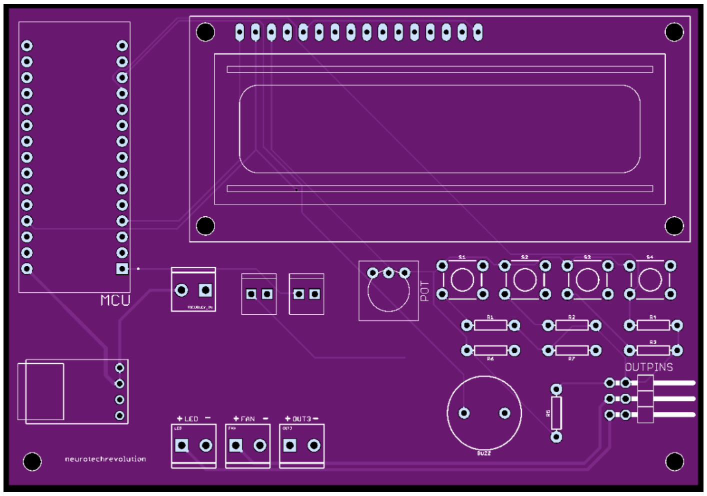
The headband will need to be one-size-fits all. The headband can be secured by wrapping it around the backplate. The back of the headband contains an interface for connecting the power supply to the circuit board on the headband. The initial prototype simply used wire connected to a terminal block. *A more stable modification planned is to include a JST connector for a more secure connection.*



Left: LED module front facing (forehead facing).
Right: Connector at the back of the headband to provide connection from the control box.

Further Design Considerations

This device is ready to be equipped with a custom PCB that integrates a constant current driver and user interface for a treatment timer, thus removing the need for the adjustable constant current driver and adds an additional feature to make treatment more convenient. This module is also believed to be unique in design and functionality compared to other LED transcranial photobiomodulation devices. *However, due to the ongoing chip shortage, this design has been postponed until further notice.* For now, the adjustable constant current driver will be used as the main controller of the device.



Control module of LED device with microcontroller, constant current driver, and user interface.