Preliminary Design of a Massage-Based Therapeutic Device for Migraines

Thejo Tattala
Mechanical Engineering
UCSD
San Diego, California
ttattala@ucsd.edu

***Abstract*—Migraines affect more than one billion people annually and are difficult to treat due to their diverse triggers, complex underlying biological mechanisms, and extreme discomfort [1]. However, due to the cost and invasiveness of current treatments, external pain relief and therapy have been a rising field of interest in migraine care. This project explores the development of a prototype for an external migraine relief bandana that uses therapeutic techniques to help reduce pain, with the aim of improving and expanding the design in the future. To develop this device, soft TPU paddles, a Arduino Board, C++, a servo, vibrating elements, and a motor with a soft cap were used in conjunction, creating a device that used pulsating paddles, vibration, and rotation for mechanical stimulation. The device was then tested for noise, durability, functionality, cost, and comfort. The results showed that while the device is portable, convenient, and easy to wear the noise of the electrical components and the uneven protrusions from the paddles into the bandana fabric can be improved. These findings suggest promising applications for noninvasive mechanical intervention in migraine relief. Future applications include using wearable electrical pads for electrical stimulation and clinical testing.**

***Index Terms*—migraines, mechanical pressure stimulation, pain relief, wearable therapeutic device**

I. Introduction

Migraine ranks second among the most prevalent neurological disorders across the globe [2]. Along with debilitating pain, migraines also cause loss of productivity and expensive treatment costs. Current treatments include medication, nerve blocks, and surgical decompression. However, these treatments are difficult to administer as they can be expensive, painful, invasive, and even addicting in the case of prescription drugs. Although there has been a rise in external therapy, including but not limited to cold therapy, massages, and electrical stimulation, current external migraine relief devices in the market cost hundreds of dollars, are bulky, and remain ineffective for casual everyday use, such as at work or school. Therefore, a wearable device that can be used for everyday purposes and offers fast, temporary external relief is impactful. Offering discreet, accessible intervention is vital in improving patient care and decreasing migraine-associated healthcare costs. Current research includes mechanical pressure alleviation through massage therapy, headbands with pressure application and cold therapy, and osteopathic manipulation. However, these techniques are not automated and sometimes require the physical presence of a healthcare professional. This research introduces a wearable solution based in massage mechanics, tailored for everyday use. Incorporating a rotating motor, vibrating components, and a TPU filament-based compression system for pressure variation, the design improves upon current technology through accessible, affordable, wearable therapy with multiple modes of pain-relief. The purpose of this paper is to present the design, functionality, and potential impact of this device, highlighting how it can provide an automated, discreet, and cost-effective alternative for migraine management.

II. Literature Review

Early approaches to migraine relief often relied on rudimentary methods of mechanical and thermal stimulation. For example, a 1993 study explored the use of ice packs and rubber disks to apply local scalp pressure as a means of reducing migraine pain [7]. At the time, such methods were among the few accessible interventions available prior to the development of modern pharmacological treatments. These approaches reflected early interest in cold therapy, pressure stimulation, and massage-inspired techniques, which would later evolve into more advanced and clinically accepted practices.

The role of massage in migraine management illustrates this shift. In 1998, a study demonstrated that targeted massage therapy, particularly at the back of the neck, the base of the skull, and the sub-occipital fibers, yielded both short- and long-term benefits [3]. Patients reported increases in headache-free days, decreases in headache severity, and secondary benefits such as reduced anxiety and fewer somatic symptoms. This study was among the first to establish massage as a promising therapeutic intervention, at a time when it was not yet widely accepted as a medical treatment.

Subsequent research expanded to compare massage therapy with other physical treatments. A study in 2005 argued that physical therapy may be more effective than massage in reducing migraine-related pain [5]. In the same year, Karabulut investigated behavioral strategies used by patients with migraines and tension-type headaches, noting that while cold application and isolation were effective, pressing directly on the pain site provided limited benefit for migraine patients [6]. These findings underscored the importance of tailoring physical interventions to specific headache types rather than applying generalized treatment strategies.

More recent work has broadened the scope of physical interventions to include osteopathic manipulation. A paper in 2022 reviewed techniques such as craniosacral therapy and chiropractic manipulation, finding evidence that such methods can reduce migraine frequency, intensity, and reliance on medication [4]. However, these authors emphasize that osteopathic approaches are best viewed as complementary rather than stand-alone treatments, and that further research is needed to establish their efficacy.

Taken together, the literature reflects a progression from simple physical remedies toward more structured, clinically guided interventions. While mechanical and massage-based approaches show promise, findings remain mixed, highlighting the need for continued innovation in accessible, non-invasive devices for everyday migraine relief.

III. Methods

The prototype consisted of a modified double-layered fabric headband, within which the mechanical and electronic components were embedded. The headband was opened along its center seam and terminal edges to allow insertion of components and routing of wiring to an external Arduino Uno R3 microcontroller and breadboard through the tail ends. To provide mechanical stimulation, custom applicators were fabricated using 3D-printed thermoplastic polyurethane (TPU), chosen for its flexibility and biocompatibility. Rectangular TPU paddles were affixed to servo horns, enabling 90° oscillatory motion against the skin. This configuration simulated a finger-like massage. Each paddle was enclosed in a removable cloth sleeve with raised surface bumps to provide localized pressure; sleeve geometry was modular, allowing customization of pressure distribution. Two paddle–servo assemblies were powered by 5V and controlled via Arduino programming in C++. Additional modes of stimulation were incorporated to broaden therapeutic options. The second mode consisted of two miniature 3V vibrators integrated into the headband, delivering localized vibration. The third mode employed a 5 V DC motor with an attached spherical TPU dome, designed to rotate continuously against the skin to mimic circular massage at a focal point. Unlike the servo-driven paddles, both the vibrators and DC motor operated directly from their power supplies without additional programming. The final system offered three distinct modalities of mechanical stimulation (oscillatory pressure, vibration, and circular massage) within a wearable headband format. The modular design enabled application to multiple anatomical regions, including the temples, wrist, thigh, joints, and back.

To evaluate the prototype, multiple tests were conducted to assess mechanical performance, acoustic output, usability, durability, and cost-effectiveness.

a) Vibration Testing.: The intensity of mechanical stimulation was measured using a smartphone accelerometer application. Three independent trials were conducted with the device operating in typical modes. Both average and peak vibration amplitudes were recorded to quantify the consistency and strength of stimulation.

b) Acoustic Testing.: Noise levels during device operation were measured using an Apple Watch decibel application. Measurements were taken for the overall device as well as for individual components, including vibrators, servo paddles, and the rotating motor. All measurements were performed in a quiet environment.

c) Usability and Comfort Testing.: A convenience sample of 8–12 adult participants evaluated the headband during a 10-minute wear session. Participants completed a short survey rating ease of donning, comfort, perceived pressure, perceived soothing, and discreteness on a five-point Likert scale. Open-ended feedback on fit and experience was also collected.

d) Durability Testing.: The device underwent 100 on/off cycles and three accidental drops from approximately 75 cm onto a wooden surface to simulate everyday handling. The headband was additionally flexed 50 times. After testing, all components were inspected for functional integrity, detachment, or breakage.

e) Cost and Portability Assessment.: A bill of materials (BOM) was compiled for all wearable components, excluding the Arduino Uno R3 and breadboard. The device weight and maximum dimensions were recorded to evaluate portability and feasibility for daily use.

IV. Results

A. Vibration Testing

Vibration intensity was quantified using a smartphone accelerometer application. Measurements were taken across three independent trials, with a sampling interval of 30 ns. In the first trial, the average vibration amplitude was approximately 0.1 m/s^2 with a peak of 1.6 m/s^2. The second trial yielded a similar average of 0.1 m/s^2 but a lower maximum of 0.4 m/s^2. The third trial again averaged 0.1 m/s^2 with a maximum of 0.7 m/s^2. These results indicate low baseline vibration amplitudes with variability in peak intensities across trials.

B. Acoustic Testing

Acoustic measurements were conducted using an Apple Watch decibel application. The overall device noise output was measured at 58 dB. Mode-specific measurements indicated 60 dB for the vibration module, 45–60 dB for the servo paddle assembly depending on movement phase, and 55 dB for the rotating motor mode. These values place the device within the range of conversational speech (approximately 60 dB). While acceptable for casual environments, the measured levels suggest that the prototype is not as quiet as originally intended, highlighting the need for quieter actuator components in future iterations. Table I summarizes the noise measurements.

C. Usability and Comfort Testing

A convenience sample of 8–12 participants evaluated ergonomics and user acceptance during a 10-minute wear session. Quantitative survey responses, collected on a five-point

TABLE I
NOISE LEVELS (DB) MEASURED DURING DEVICE OPERATION.

Mode	Noise Level (dB)
Overall device	58
Vibrator only	60
Servo paddles	45–60
Motor only	55

Likert scale, yielded median scores ≥ 4 for ease of donning and overall comfort, meeting the predefined success criteria. Qualitative feedback indicated that the headband was easy to wear, small in size and convenient for casual use. However, participants noted that the device was relatively noisy and that the paddle pressure felt uneven and bumpy. These observations suggest that while the wearable design was broadly acceptable, noise reduction and paddle geometry refinement are required to enhance user experience.

D. Durability Testing

The durability of the prototype was assessed through repeated mechanical and operational stress tests. The device survived three consecutive drops of the circular motor component from desk height ($\sim$75 cm) onto a wooden surface without functional failure. Furthermore, 100 consecutive on/off operational cycles were completed successfully. The servo paddle subsystem, however, exhibited weaknesses: the servo horns detached repeatedly when dropped. Reinforcement with double-sided tape and ribbon wrapping was implemented, after which stability improved substantially. These findings indicate that while the system demonstrated robustness under repeated use, improvements to servo attachment methods are necessary to ensure long-term reliability.

E. Cost and Portability Benchmarking

A bill of materials (BOM) was prepared to assess affordability relative to existing commercial migraine relief devices. Excluding the Arduino Uno R3 controller and breadboard (treated as external to the wearable), the estimated BOM totaled approximately \$13.30. The primary components included two DC motors (\$8), two servo motors (\$4), and vibration motors (\$1.30). TPU filament and other consumables contributed minimally to cost. A breakdown of costs is provided in Table II. The device weight was estimated at under 150 g, and the form factor allowed storage in a pocket or small bag. These results support the claim of affordability and portability compared to commercial systems typically priced above \$100.

TABLE II
BILL OF MATERIALS (EXCLUDING ARDUINO UNO R3 AND BREADBOARD).

Component	Cost (USD)
2 × DC motors	8.00
2 × Servo motors	4.00
Vibrator motors (pair)	1.30
TPU filament (1 in^3)	negligible
Total	**13.30**

.

V. DISCUSSION

The prototype wearable migraine relief device was evaluated through mechanical, acoustic, usability, durability, and cost assessments. The vibration tests demonstrated low baseline amplitudes (average 0.1 m/s^2) with intermittent peaks up to 1.6 m/s^2. This indicates that the device provides detectable mechanical stimulation while avoiding excessive force that could cause discomfort. However, variability across trials suggests that refinement in actuator control or calibration may improve consistency.

Acoustic testing revealed that the device operates at 55–60 dB depending on the active mode, comparable to conversational speech. These noise levels are higher than initially intended for a discreet wearable. Given that noise can be a trigger for migraines or make preexisting symptoms worse, future iterations could benefit from quieter vibration motors or improved mechanical damping to reduce operational noise.

Usability testing with 8–12 participants indicated moderate acceptance of the device's fit and comfort, with median ratings of 3/5 or higher for ease of donning, comfort, and perceived pressure. Participants reported that the headband was portable and convenient for casual use; however, the uneven pressure from the paddle sleeves and the audible noise were noted as drawbacks. These findings suggest that the current design meets basic ergonomic requirements but could be optimized for user experience, particularly in the refinement of pressure distribution and acoustic footprint. The design may benefit from an additional layer of noise-control and padding or alternate motors and fabric.

Durability tests demonstrated that the device could withstand repeated on/off cycles and minor drops without critical failure. The servo paddles, however, were prone to detachment when subjected to impact, requiring reinforcement with tape and ribbon. This highlights the need for improved attachment methods and robust mechanical design to ensure long-term reliability in everyday use.

Cost analysis and portability assessment support the design's accessibility. The headband components (excluding the Arduino and breadboard) totaled approximately \$13.30, substantially lower than commercial devices, which typically cost over \$100. The lightweight and compact design further reinforces its suitability for portable, everyday application.

Overall, these results indicate that the prototype successfully demonstrates the feasibility of a low-cost, multi-modal wearable device for mechanical stimulation. Key advantages include affordability, portability, and user comfort. Limitations include noise levels, paddle pressure inconsistency, and minor mechanical fragility. Future work should focus on quieter actuators, improved paddle geometry, and integration of force feedback for more precise pressure control. In this study, electrical stimulation pads, such as transcutaneous electrical nerve stimulation (TENS), were not included due to their requirement for direct skin contact and their inability to transmit signals effectively through fabric. Future iterations of the device could integrate electrical stimulation either by incorporating flexible electrodes into the bandana or by replacing the fabric interior with a material capable of providing direct skin contact, thereby enabling safe and effective electrical stimulation. Expanding usability testing to a larger and more diverse sample would also strengthen the generalization of findings.

While these tests do not evaluate clinical efficacy, the device shows potential as a practical, non-invasive tool for temporary mechanical relief, complementing existing migraine management strategies.

VI. Conclusion

This study aimed to develop a prototype of a mechanical pressure relief device for migraine treatment. The results show that while noise and comfort are areas for improvement, the device shows promising results in migraine therapy. This research opens doors to sustainable, affordable, and safe healthcare interventions as opposed to costly devices in the market. Future research should explore quieter machinery, padded fabric, electrical stimulation, and incorporation of advanced wearable technology.

VII. Acknowledgments

The author would like to thank Biomedical Engineering Society UCSD and the San Diego Undergraduate Tech Conference organizers for their support and guidance throughout this project. We also extend our gratitude to Annika O'Rourke and Xavier Lu for their valuable assistance in developing the prototype and conducting background research.

References

[1] S. K. K. Tfelt-Hansen, "Migraine: a review on its history, global epidemiology, risk factors, and current treatment strategies," *PMCID: PMC8904749*, 2022. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8904749/

[2] J. Doe et al., "Migraine: an underestimated neurological condition affecting billions," *PMCID: PMC9506374*, 2022. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9506374/

[3] M. Hernandez-Reif, J. Dieter, T. Field, B. Swerdlow, and M. Diego, "Migraine headaches are reduced by massage therapy," *Int. J. Neurosci.*, vol. 96, pp. 1–11, 1998. [Online]. Available: https://doi.org/10.3109/00207459808986453

[4] H. V. Sharath, P. T. Nadipena, M. I. Qureshi, and P. Phansopkar, "A review on osteopathic manipulation in patients with headache," *Cureus*, vol. 16, no. 8, e66242, 2024. [Online]. Available: https://doi.org/10.7759/cureus.66242

[5] D. M. Biondi, "Physical treatments for headache: a structured review," *Views and Perspectives*, 2005.

[6] B. B. A. G. and N. Karabulut, "Pain-relieving factors in migraine and tension-type headache," *Int. J. Clin. Pract.*, vol. 59, pp. 760–763, 2005.

[7] N. Vijayan, "Head band for migraine headache relief," *Headache*, vol. 33, no. 1, pp. 40–42, 1993.

float

...

Appendix

This appendix presents the supplementary figures for the device in the paper.

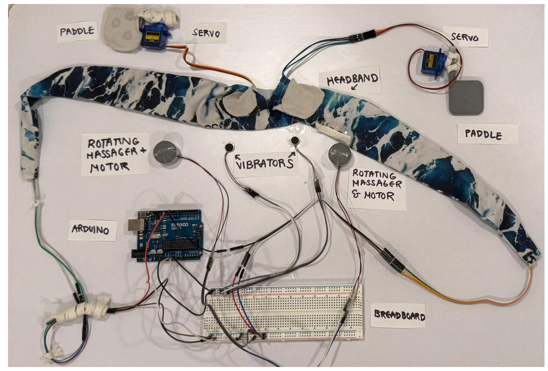

Fig. A1. Schematic of the migraine relief device. The bandana serves as the fabric base, while TPU paddles are attached to servo horns capable of 90° rotation. Each paddle can be fitted with a sleeve containing pressure points. The Arduino controls the paddles, two vibration motors, and two DC motors with TPU domes to deliver targeted mechanical stimulation.

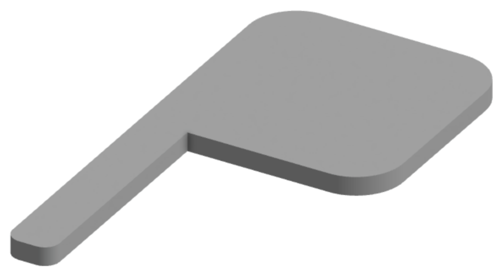

Fig. A2. CAD of TPU paddle.

```
#include <Servo.h>

// creating the servo object to control the servo rotating the paddles.
Servo paddleRotator;
Servo paddleRotator2;
int pos = 0;
  void setup() {
      paddleRotator.attach(11);
      // attaches the servo on pin 11 to the servo object (paddleRotator).
      paddleRotator2.attach(10);
    }

void loop() {
  // Sweep from 0 to 180 degrees
  for (pos = 0; pos <= 90; pos += 1) {
    paddleRotator.write(pos);
    delay(15);  // Wait 15ms for the servo to reach the position
  }

  // Sweep from 180 to 0 degrees
  for (pos = 90; pos >= 0; pos -= 1) {
    paddleRotator.write(pos);
    delay(15);
  }
  for (pos = 0; pos <= 90; pos += 1) {
    paddleRotator2.write(pos);
    delay(15);  // Wait 15ms for the servo to reach the position
  }

  // Sweep from 180 to 0 degrees
  for (pos = 90; pos >= 0; pos -= 1) {
    paddleRotator2.write(pos);
    delay(15);
  }
}
```

Fig. A3. Code for Arduino and servos.

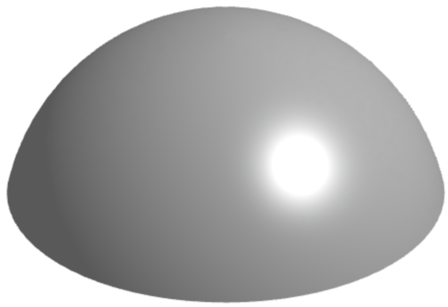

Fig. A4. TPU cap for DC motor (rotating element).

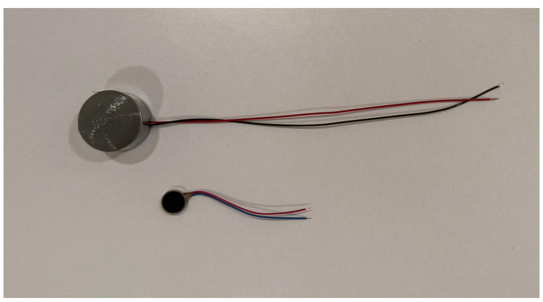

Fig. A5. Rotating DC motor with TPU cap (top) and vibrating element (bottom).

Fig. A6. Final assembled device integrated into bandana form factor.