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Evaluation of Dual-Wavelength LED Light Irradiation of the Skull for Alleviating Neck and Shoulder Pain and Improving Heart-Rate Variability †

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Abstract

We investigate the use of non-invasive, dual-wavelength (630 nm red/940 nm near-infrared) LED irradiation of the skull for relieving chronic neck and shoulder pain. A low-energy device was applied bilaterally for 15 min, with assessments of pain performed using the numeric rating scale (NRS), muscle relaxation assessed via infrared thermography, and autonomic function determined through heart-rate variability (HRV) analysis. The results demonstrated a mean NRS score reduction of 2.4 points, a 0.6 °C increase in cervical skin temperature, and a significant increase in HRV's root mean square of successive differences, indicating improved autonomic regulation. This technique shows promise for effectively relaxing muscles, alleviating pain, and enhancing autonomic function.

Keywords: red light; near-infrared light; neck and shoulder pain; heart rate variability (HRV)

1. Introduction

Shoulder and neck discomfort is highly prevalent in modern society. According to the Ministry of Health and Welfare in Taiwan, approximately 55% of individuals report musculoskeletal discomfort in these regions. Prolonged poor posture, repetitive muscular load, and soft-tissue injuries from sprains or impacts can lead to muscular strain, ligament damage, and subsequent acute or chronic inflammation. As a result, neck and shoulder pain have become increasingly common conditions in the 21st century. Although traditional treatment modalities—such as medication, physical therapy, and acupuncture—are well established, growing interest has shifted toward non-pharmacological and non-invasive adjunctive techniques [1–5].

Photobiomodulation (PBM) using LEDs has shown potential in promoting tissue repair, reducing inflammation, and modulating pain perception. The cranial aponeurotic system, including the galea aponeurotica, is functionally linked to the cervical, thoracic, and lumbar spine through the myofascial chain. Postural imbalance and long-term muscle tension may cause fascial asymmetry and the formation of trigger points near the skull surface [6–9].

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To accurately identify cranial target regions for photonic stimulation, we adopted the Yongtian Cranio-Sacral Therapy framework, which traces interconnected myofascial pathways along the axial skeleton. This mapping approach identifies shoulder–neck reflex points located in specific regions of the cranial vault. By integrating this concept with dual-wavelength LED PBM application, our goal is to assist physical therapists and manual practitioners in providing enhanced relief of neck and shoulder discomfort, while simultaneously promoting musculoskeletal health [9].

2. Materials and Methods

2.1. Device Specification

A custom-designed dual-wavelength LED PBM device (Kaohsiung, Taiwan) was utilized in this study, delivering low-energy light at 630 nm and 940 nm. Each illumination module consisted of four LEDs, which were arranged in two bilateral groups to ensure uniform cranial surface coverage (Figure 1). The charger used was a Nichia (model: UB-06P), which was made in China.



Figure 1. Dual-wavelength LED light source module.

The wavelength selection was based on complementary photobiological mechanisms. Red light at 630 nm primarily acts on cytochrome-c oxidase within the mitochondrial respiratory chain, promoting adenosine triphosphate synthesis, microcirculation enhancement, and improved oxygen delivery to superficial tissues. Conversely, the 940 nm near-infrared wavelength provides deeper penetration into neural structures, modulating nociceptive pathways and autonomic regulatory mechanisms via photothermal and photochemical effects. The combined application allows simultaneous activation of superficial and deep tissues, enabling a multi-target therapeutic response. The device meets the international standard for the photobiological safety of lamps and lamp systems (IEC 62471 [10], CNS 15592 [11]), as well as photobiological safety standards (2006 edition), and has been certified by a TAF-accredited laboratory to ensure safe irradiance levels.

2.2. Experimental Protocol

The experimental protocol consisted of the following steps.

1. Pre-treatment Assessment: Participants were informed about the procedure and instructed to report any discomfort. After a 10 min seated rest, pain intensity was assessed using the 11-point Numeric Rating Scale (NRS), where 0 = no pain and 10 = the worst imaginable pain.
2. Baseline Data Collection: Paraspinal muscle temperature was measured using a thermal imager (Teledyne FLIR LLC, FLIR T530, Portland, OR, USA, Figure 2).
3. Fingertip Photoplethysmography (PPG) sensor attachment for HRV monitoring: A fingertip PPG sensor (PLUX BVP Blood Volume Pulse Sensor, Brand: PLUX Model: Biosignalsplux BVP Finger clip sensor, Manufacturer PLUX Wireless Biosignals, S.A., Lisbon, Portugal) was attached to acquire HRV signals for 5 min (Figure 3).

4. Cranial marking: With the intersection of the sagittal and lambdoid sutures used as the reference location, the irradiation points were marked by moving approximately 2.7 cm toward the coronal suture bilaterally (Figure 4).
5. Dual-wavelength irradiation: Modules were positioned on both sides of the skull for 15 min of irradiation (Figure 5).
6. Post-treatment Assessment: NRS rating, thermography, and HRV measurements were repeated, following the same procedures as baseline.

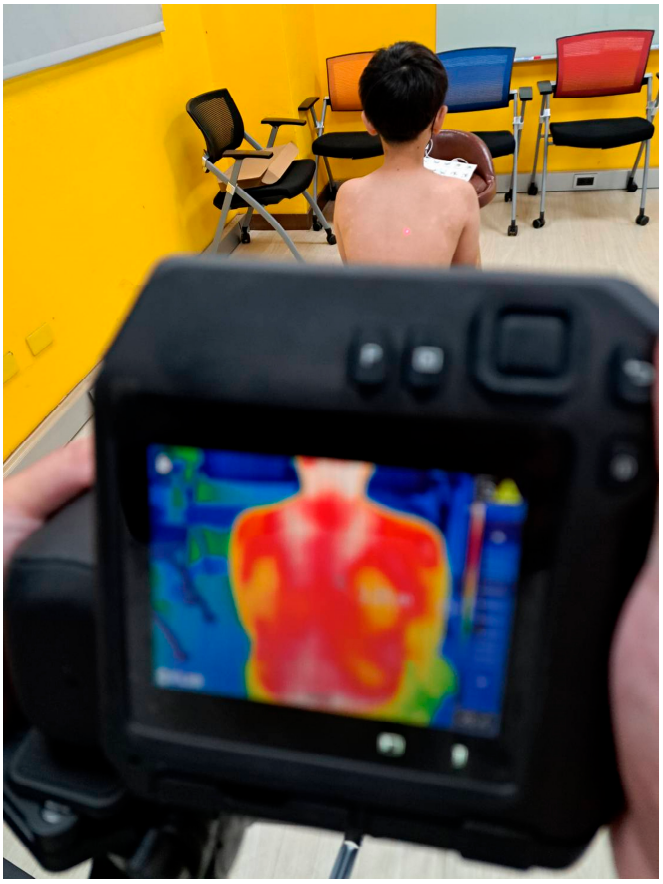


Figure 2. Thermal imager used for temperature measurement.

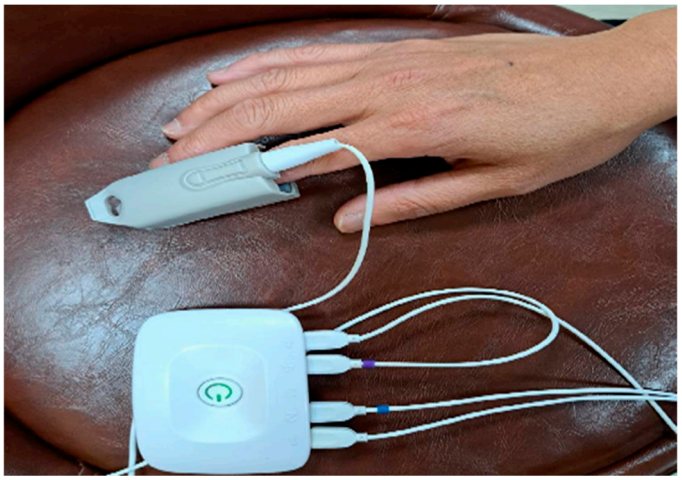


Figure 3. Fingertip PPG sensor attachment for HRV monitoring.

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Figure 4. Marking irradiation sites on the skull.

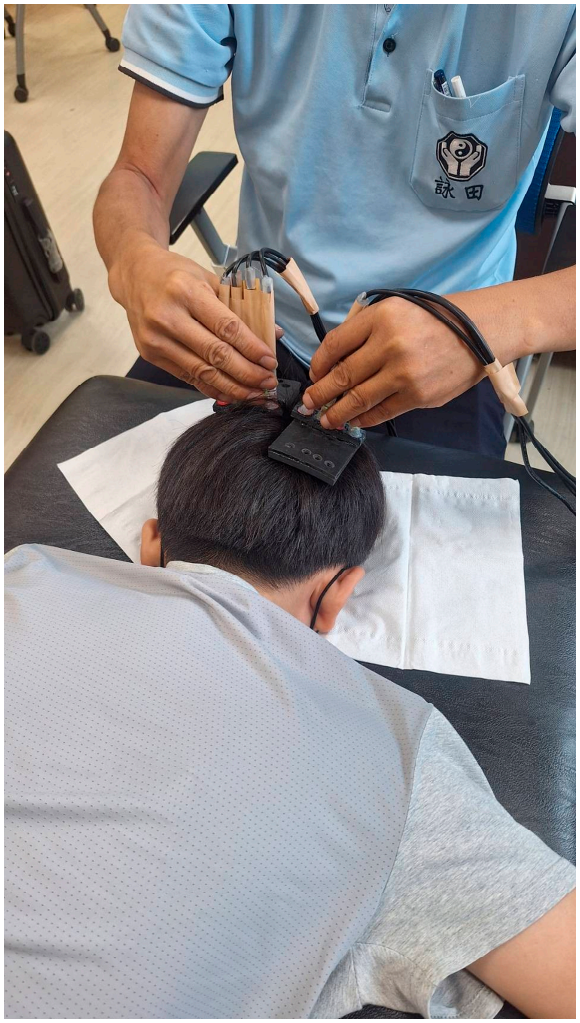


Figure 5. Dual-wavelength LED irradiation procedure.

2.3. Data Analysis

Data analysis was conducted by quantifying the differences in pre- and post-intervention values for NRS, temperature, and HRV. Thermal imaging data, together with PPG signals obtained using the PLUX HRV Heart Rate Analysis Expansion Module (Brand: PLUX, Model: Open Signals HRV Add-on, Manufacturer: PLUX Wireless Biosignals, S.A., Lisbon, Portugal, Figure 6), were processed to evaluate autonomic function. The Heart Rate Variability (HRV) add-on for the OpenSignals (r)evolution Hybrid-8 software is designed

to process Electrocardiography (ECG) and Blood Volume Pulse (BVP) sensor data to extract Beat-to-Beat interval series from which temporal, spectral, and nonlinear HRV parameters are computed. All the algorithms were implemented according to the Standards of Measurement, Physiological Interpretation, and Clinical Use devised by the joint European Society of Cardiology and North American Society of Pacing Electrophysiology Task Force.

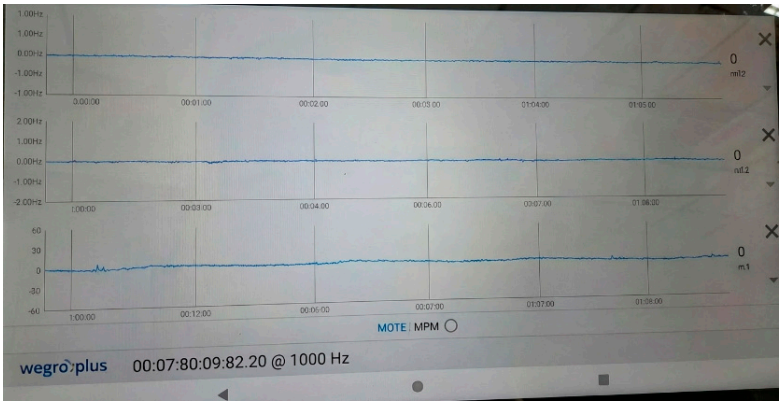


Figure 6. Computer-based physiological data acquisition.

3. Results and Discussion

Pain relief was evaluated 3 min post-irradiation across all subjects. The mean NRS score decreased by 2.4 points ($p < 0.001$), indicating significant analgesic efficacy. Individual responses were as follows.

- Subject A: −3.6 points ($p < 0.01$), analgesic duration: 5 days.
- Subject B: −1.5 points ($p > 0.05$), duration: 1 day.
- Subject C: −2.0 points ($p > 0.05$), duration: 2 days.

The improvement in Subject A exceeded the minimal clinically important difference, demonstrating both statistical and clinical significance (Table 1).

Table 1. NRS pain score reductions.

Subject	Mean Difference	Sample Size (N)	Duration (Days)
A	–3.6	3	5
B	–1.5	3	1
C	–2.0	3	2

Thermal imaging indicated increased cervical temperature after treatment, reflecting enhanced microcirculation. The greatest improvement occurred in Subject A (+1.68 °C), while Subjects B and C exhibited progressively attenuated responses, potentially due to chronicity-related microvascular compromise (Table 2).

Table 2. Temperature change by subject.

Subject	Mean ΔTemp (°C)	Standard Deviation (°C)	Sample Size
A	+1.68	0.661	9
B	+0.27	0.654	9
C	−0.06	0.133	9

HRV (RMSSD Difference Value) analysis showed significant differences across subjects. Single-factor Analysis of Variance confirmed distinct autonomic responses ($F(2,6) = 14.86$, $p < 0.01$).

- Subject A: significant parasympathetic enhancement (ΔHRV: +51, +62, +71 ms; mean +61.3 ms).
- Subject B: mild improvement (ΔHRV: +11, −9, 1 ms; mean +1.0 ms).
- Subject C: predominantly negative response (ΔHRV: −61, −65, +2 ms; mean −41.3 ms), suggesting impaired modulation.

These results suggest that individuals with less chronic pain may demonstrate stronger positive autonomic responses to PBM (Figure 7).

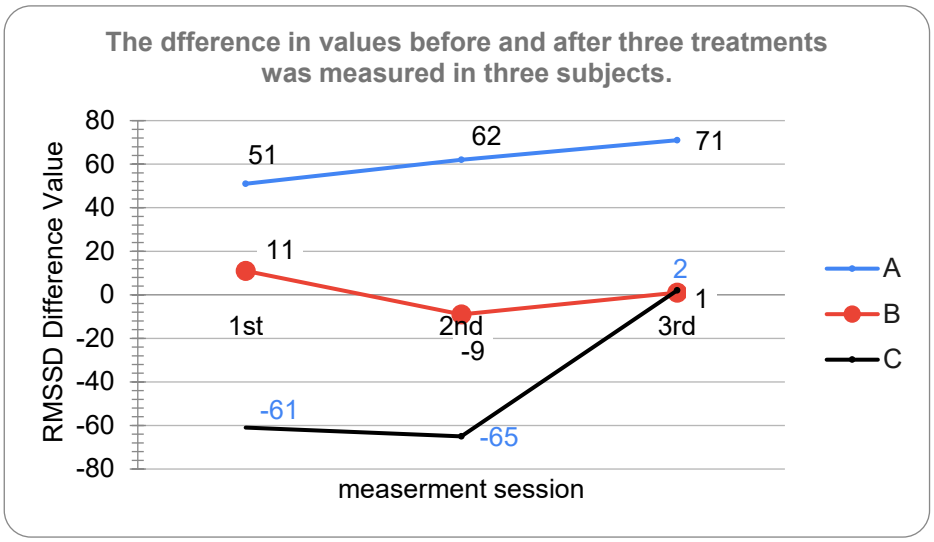


Figure 7. RMSSD difference bar chart.

4. Conclusions

Dual-wavelength transcranial LED irradiation provides meaningful multi-dimensional therapeutic benefits. NRS scores significantly decreased, cervical temperature increased, and HRV indicators exhibited subject-specific autonomic improvements. The variability observed highlights the influence of individual physiological conditions, such as chronic pain, on treatment outcomes. Overall, this technique shows potential as a safe, non-invasive modality for musculoskeletal relaxation and autonomic regulation, supporting future clinical translation and personalized treatment strategies.

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Institutional Review Board Statement: This pilot study evaluated the effect of non-invasive LED light therapy applied to the cranium on shoulder and neck pain. The LED device was certified for photobiological safety by a nationally accredited laboratory in accordance with the Photobiological Safety Testing Report of Light Sources and Light Source Systems, ensuring compliance with IEC 62471 (CNS 15592) photobiological safety standards (2006 edition). Participant assessments were conducted using non-invasive instruments, including thermal imaging and photoplethysmography (PPG), with minimal risk comparable to routine daily activities. All participants provided informed

consent prior to participation. To protect participant confidentiality, all data were anonymized during collection and analysis. The study was conducted without prior institutional review board (IRB) approval. However, all procedures were designed and implemented in accordance with the ethical principles of the Declaration of Helsinki, and appropriate safeguards were incorporated to protect participant welfare and rights.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest.

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