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Technical Note

Efficacy of LED Infrared Warming in the Periphery of the Human Body – First Investigations in a Subject using Thermography

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Abstract

In this technical report, we present for the first time a newly developed multimodal light-emitting diode (LED) pad for photobiomodulation (PBM). In order to demonstrate the range of possibilities for its application, we carried out a comparison of measurements with and without infrared (IR) LEDs in a volunteer, and are presenting the results. The pad consists of several components, which are mainly composed of LEDs of different modalities (IR, red, yellow, and blue). This multicolor system was applied to a peripheral area of the body in the volunteer. Thermal imaging of the region of interest showed that additional stimulation with IR LEDs increased temperature by about 113% compared to stimulation without IR LEDs. Our results concluded that non-visible IR LED stimulation techniques could be extremely helpful in improving the quality of PBM.

Keywords

Photobiomodulation; LED (light-emitting diode) pad; thermography; thermal imaging; infrared LED; red LED; yellow LED; blue LED; peripheral effects

1. Introduction

An infrared (IR) LED (light-emitting diode) is a special diode, which emits light in the near-infrared wavelength at a range of 700 nm to 1000 nm. This area of the light spectrum is not visible to the human eye but can be measured with radiation detectors like photodiodes and phototransistors. It is less known that IR LEDs were the first LEDs to be produced, and were developed even before the first red light-emitting diodes. In 1961, Robert Biard and Gary Pittman patented the first gallium arsenide (GaAs)-based infrared LED produced at Texas Instruments [1]. Until the early 1970s, the only available LEDs – red and infrared LEDs – were very expensive. In comparison, the current price of a large quantity of IR LEDs is very low. Infrared LEDs are manufactured with different wavelengths.

Human body stimulation with different optical modalities (including IR LEDs) is a novel form of non-invasive photobiomodulation (PBM), and it has shown therapeutic potential in a variety of conditions [2, 3]. Such a method can be combined with non-invasive LED stimulation using other wavelengths (e.g., the use of red, yellow, or blue LEDs).

The present article outlines the development and first-time application of a new phototherapy pad applied to the peripheral area of a human volunteer. Non-invasive thermal imaging was used to investigate the temperature alterations of the skin from the new stimulation method [4].

2. Methods

2.1 Phototherapeutic Pad

A new phototherapeutic pad (Suyzeko, Shenzhen, China) based on polychromatic light therapy is being presented for the first time in a scientific article here. The possible values of measurement for treatment in a volunteer are also briefly shown. The pad consists of several components, which are mainly composed of LEDs of different modalities (IR, red, yellow, and blue). This multicolor system can be applied to any area of the body. The system consists of two pieces of pads, a control unit, a power adaptor, a power cable, and a manual (see Figure 1).

Figure 1 Phototherapeutic pad using different modalities of LEDs (Suyzeko, Shenzhen, China). The picture shows an example of the application on the hand, but only measurements on the feet were carried out for the experiments in this work.

The following LEDs are integrated into the system and can be controlled and activated both individually and in various combinations through the control unit: IR, red, yellow, and blue (see Figure 2 and Table 1). The geometrical dimensions of each pad are 28.3 x 25.0 cm, with the active area in which the LEDs are integrated being 20 x 17 cm.

Figure 2 Different colors of the pads.

Table 1 shows the number and wavelength of individual LEDs, the total number of LEDs, and the wavelength range.

Table 1 Kind of LED, pieces of LEDs, and wavelengths.

LED (light-emitting diodes)	Pieces	Wavelength (nm)
Infrared	84	810
Red	70	660
Yellow	28	589
Blue	28	405
Total number/range	210	405 – 810

The intensity of each LED was 0.2 W. The spectral power density was not specified by the manufacturer. Unless an infrared filter is installed, digital cameras are usually sensitive to both visible light and infrared light. With the help of active IR LED pads, the functionality of infrared remote controls can easily be checked (Figure 3).

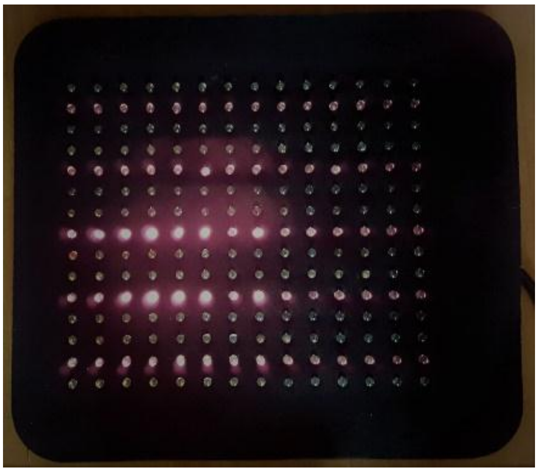

Figure 3 Active IR LEDs implemented in one pad.

2.2 Experiment, Volunteer and Procedure

A 61-year-old male volunteer subject was given stimulation using the new phototherapy pad, and monitored before, during, and after stimulation by thermal imaging. The volunteer neither had any neurological, cardiovascular, or respiratory diseases, nor was taking any medication at the time of examination. The experiment, which included only non-invasive measurement methods (LED stimulation and thermography), was approved by the local ethics committee of the Medical University of Graz, and the measurements were performed according to the declaration of Helsinki.

Before receiving the stimulation, the volunteer sat for 5 min on a chair to adapt to the room conditions (temperature). Then, thermal images of the region of interest were taken 5 min before, every 5 min during, and 3 min after stimulation. Thermal images of the same locations were taken at the end of the stimulation process. Figure 4 shows the experimental flow chart.

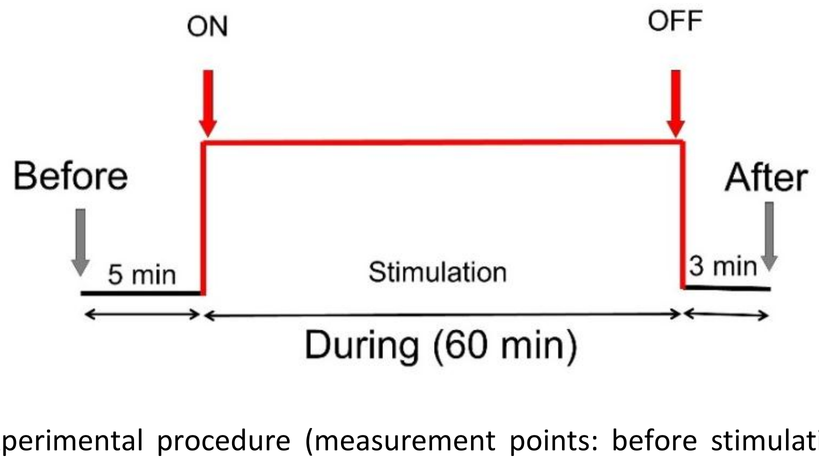

Figure 4 Experimental procedure (measurement points: before stimulation, every 5 minutes during stimulation (5 – 60 min), and 3 minutes after stimulation.

The experimental procedure consisted of collecting two sets of measurements, which was carried out on two different days in almost the same manner, at the same time of the day and on the same person (also same room temperature of 23.3 °C; same humidity of 55%). The only difference between the two sets of measurements was that an additional 84 invisible infrared

LEDs (810 nm) were activated in the second set of measurements. The aim was to determine any possible differences in the evaluation parameters (temperature changes).

2.3. Thermal Imaging and Data Analysis

Thermal imaging was performed using an infrared camera Flir i7 (Flir Systems Inc., Portland, USA). This imaging technology allows the simultaneous measurement of temperatures at multiple points on the surface of the skin, and also acts as a reference for the surrounding temperature. The camera operates at a wavelength range of 7.5–13 µm. The focal distance of the infrared lens is f = 6.8 mm. The infrared resolution is 140 x 140 pixels, and the accuracy of the camera lies at ±2% of the reading. The data were transferred to a notebook (Acer, Aspire 5, Acer Inc., Taipei, Taiwan) using Flir Tools software (April 2020, Flir Systems Inc., Portland, USA). Thermal images for evaluating temperature changes in the volunteer were taken 5 min before, during (at 5-minute intervals), and 3 min after stimulation. The region of analysis for the thermographic measurements included areas around the right side of the right foot of the volunteer (1 cm diameter of the region of interest: see cursor in Figures 5 and 6). In these areas, the highest temperature value was marked (see cursor in Figures 5 and 6).

3. Results

Figure 5 shows the results of the thermal images taken before, during (5 to 60 min), and after continuous red, yellow, and blue LED stimulation via the new pad. The measurement point with the highest increase in temperature (see cursor) was found at the end (60 min) of continuous stimulation (28.8 °C).

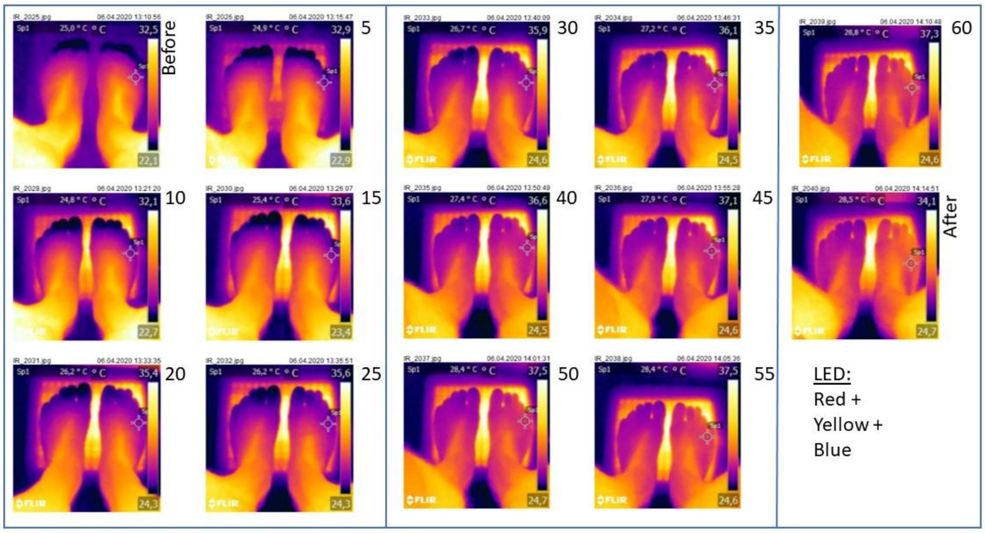

Figure 5 Thermal images. Note the increase in the temperature in the region of interest during continuous and simultaneous red, yellow, and blue LED stimulation.

Figure 6 shows the results of the thermal images taken during the second set of measurements in the same person. Again, continuous red, yellow, and blue LED stimulation was carried out. In addition, 84 non-visible infrared LEDs were activated. The highest increase in temperature in this session was also found at the end (60 min) of continuous multimodal stimulation (30.2 °C).

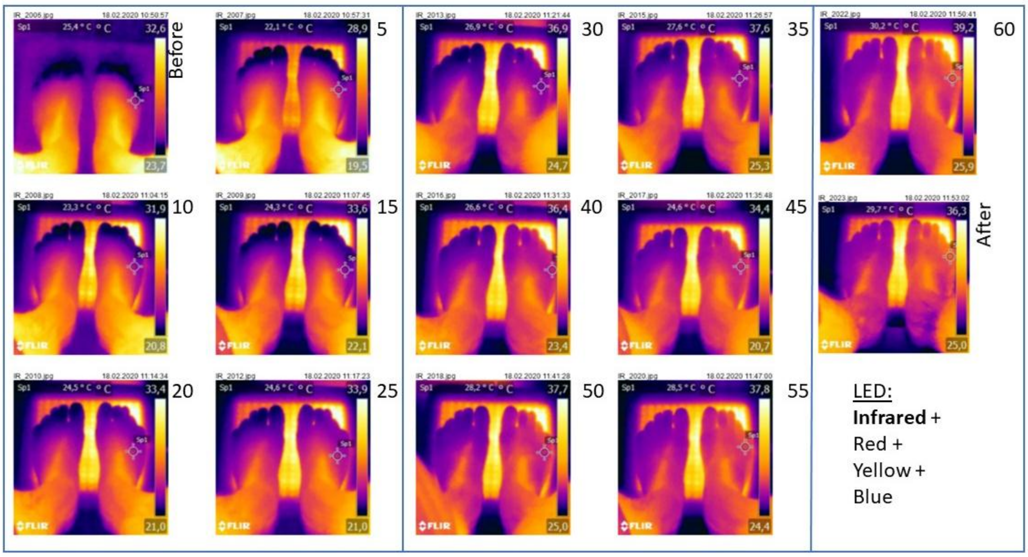

Figure 6 Thermal images. Note the high increase in the temperature in the region of interest during continuous and simultaneous infrared, red, yellow, and blue LED stimulation.

As shown in Figure 7, the use of IR LEDs had a striking effect in the results, which showed that despite similar test conditions, there was a significant increase in the temperature in the area of the subject's foot. On quantifying this effect, the measurement temperature was found to increase by about 113% compared to stimulation without using IR LEDs. The five-minute timepoint was used as a baseline because, at this point, the temperature differences between the two experiments were nearly equal (Figure 7).

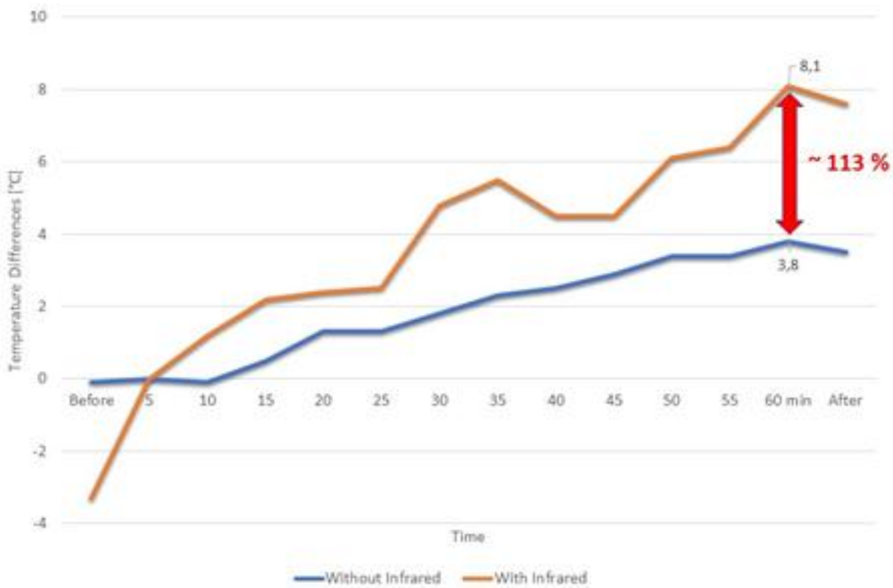

Figure 7 Temperature behavior at the measuring point of the subject's right foot. Note the significantly increased effect under the stimulation condition with the activated IR LEDs.

4. Discussion

This short technical report outlines a new non-invasive LED method for PBM that can be used for peripheral stimulation of the human skin.

The results of an animal experiment conducted recently in 2020 showed that infrared LED had significant effects on mechanical stimulation and cold allodynia. In the spared nerve injury (SNI) model of rat, an analgesic effect was observed after every treatment. However, the effect was abolished when treatment was interrupted. These findings by authors from Brazil suggest that PBM therapy may be useful as an adjunct therapy for chronic pain [5].

A study by Gavish et al. published recently in 2020 [6] showed that near-infrared PBM was found to induce a 27% increase in microcirculatory flow that increased to 54% during a 20-minute follow-up period, but red light PBM did not show a similar increase in median flow. Only ten out of twenty participants were responsive to PBM, as shown by thermal imaging. The authors demonstrated the underlying mechanism in which PBM induces arteriolar vasodilation resulting in both immediate and long-lasting increased capillary flow and tissue perfusion in healthy individuals. This response was found to be wavelength-dependent and modified by skin temperature [6].

Another study dealt with chronic obstructive pulmonary disease (COPD), which is characterized by dyspnea as well as musculoskeletal and systemic manifestations. PBM, along with light-emitting diode therapy, is an intervention that has been found to minimize or delay muscle fatigue. The aim of the study [7] was to evaluate the (acute) effects of PBMT when used in combination with laser diodes, LEDs, or magnetic field on muscle performance, exercise tolerance, and metabolic variables during a 6-minute step test in patients with COPD. The study showed that the combined application of PBM therapy and magnetic field increased the number of steps during the step test, and decreased the sensation of dyspnea and lower limb fatigue in patients with COPD [7].

The efficacy of infrared warming therapy is well known. In 1999, Mori et al. [8] showed the effects of warming the eyelids with an infrared heater in comparison with a broad-spectrum heater. The authors concluded that heating for only 5 min was necessary to increase ocular temperature and enhance comfort. In our present study, we could not show a similar immediate effect after heat stimulation for 5 min; however, this could be attributed to the fact that the technical parameters of stimulation and also the site of stimulation were very different in our study.

In our pilot investigation in a volunteer subject, the peripheral temperature was significantly increased with the use of infrared LEDs compared to the same procedure done without infrared LEDs. Additionally, the warming effect of the feeds was significantly more pronounced after using our innovative pad with infrared LEDs for the longest stimulation time (60 min) than with the use of red, yellow, and blue LEDs alone.

According to Figures 5 and 6, the pad itself heated up during the irradiation, and remained hot after the irradiation, in both cases when red LEDs were used, and when infrared LEDs were added. In addition, temperature changes in the left leg were minor, whereas the right leg underwent a more pronounced temperature elevation. A possible reason for this could be a knee injury on the right leg of the volunteer, which may have been trained more in the previous months than the left one.

In this pilot study, we have used infrared thermography as an evaluation method. It is a suitable method to quantify surface temperature changes. In the future, we want to use Laser Doppler imaging (LDI) to record any changes in microcirculation, as has already been done in similar studies in the past [6, 9-14]. The use of near-infrared photobiomodulation to increase microcirculatory blood flow, as measured by a variety of techniques including laser Doppler, was demonstrated by Gavish et al. [6], Samoilova et al. [9, 10], Schindl et al. [11, 12], Schaffer et al. [13], and Litscher et al. [14]. The effects of near IR PBM include the optimization of mitochondrial function, decrease in fatigue, and improvement of peripheral circulation [6, 9-14].

This study has several limitations. IR light can penetrate the skin and deep tissues. If patients use IR for a prolonged period of time, it may change their core temperature. Therefore, an important safety measure to be followed is to ensure that the patients do not experience hyperthermia. In our experiments, the core temperature was not recorded, which is a limitation of this study.

Due to the addition of 84 IR LEDs to the LED pad, the second experiment produced more heat in the patient's feet than the first one. Therefore, the second session had more LEDs than the first session making a direct comparison between the two sessions unequal. Another limitation of the study is that the volunteer did not have the same baseline temperature of the feet before stimulation in the two sessions.

Studies with a larger number of cases with corresponding clinical pictures are planned for future work, in order to justify or exclude possible clinical uses of the new LED pads.

5. Conclusion

In this technical report, we present a new LED pad for PBM. Through our study, we were able to show that stimulation with different modalities of LEDs resulted in different biological thermographic effects. This indicates that in addition to continuous and simultaneous red, yellow, and blue LED stimulation, non-visible infrared LED stimulation techniques may be helpful in improving the quality of PBM; however, this has to be proven further in future research.

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Author Contributions

GL designed and performed the pilot measurements and wrote the article.

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Competing Interests

The author has declared that no competing interests exist.

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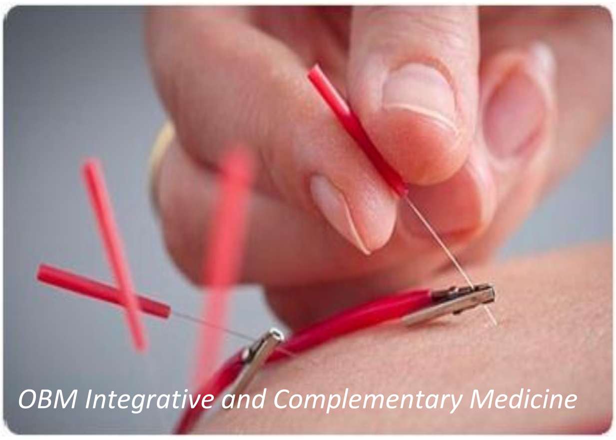
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