THE EVOLUTION OF RED AND INFRARED LIGHT THERAPY IN MODERN TIMES

JUAN GONZALEZ, PHD, CSCS, YULIANA SANCHEZ-TRINIDAD, AND KEYLA OLMEDA

INTRODUCTION

The aim of this article is to share with strength and conditioning coaches how red light therapy has evolved from its early beginnings to contemporary times, as well as to address the many benefits for athletes. In recent years, red light therapy, or photobiomodulation (PBM) as it is now referred to, has received much attention in terms of its anti-inflammatory effects and ability to enhance athletic performance (14). Red light therapy can be described as utilizing red or near-infrared (NIR) light to stimulate, heal, or regenerate damaged tissue as well as increase the quantity of antioxidants (14). The reasoning behind using PBM for enhancing sports performance is due to the stimulation of mitochondrial activity that is triggered after red or near-infrared light exposure on tissue, which results in a vigorous increase of the source of energy needed for muscle work, known as adenosine triphosphate (ATP) (14).

Historically, PBM was initially utilized to prevent muscle damage and fatigue with animal models, specifically rats (14). These models were carried out by irradiating the skeletal muscles with PBM before a bout of intense exercise followed by an assessment of creatine kinase (CK) levels to measure the extent of muscle damage (14). Another experimental study, which similarly utilized animal models, found that PBM was able to enhance defenses against oxidative stress, inhibit inflammation, and reduce CK activity (14). These early findings with animal models were vital in order to prove the effectiveness of PBM and begin clinical trials for the prevention of muscle damage, improvement of muscle performance, and enhancement of exercise recovery in humans (14).

Modern PBM has the merit of becoming a valuable tool for strength and conditioning coaches. Research shows that sleep, which is an important factor in the process of recovery and preventing overtraining syndrome, can be enhanced with PBM therapy (30,38). Furthermore, increased skeletal muscle performance and an improved defense against damage to skeletal muscle tissue have been associated with PBM therapy (31). Research also suggests that strength training with PBM could be superior to strength training alone (16). These are but a few of the numerous benefits that red light therapy has to offer.

THE HISTORY OF RED LIGHT THERAPY

THE ELECTROMAGNETIC SPECTRUM

The electromagnetic (EM) spectrum is formed with a variety of EM radiation as wavelengths or particles that travel through space (35). It is a representation of all forms of light that are visible and not visible to the human eye (35). Wavelength increases towards the right from gamma rays to radio waves, while frequency increases to the left from radio to gamma rays (35). PBM wavelengths range from 400 – 1,100 nm as a proper dose that reaches the cells to promote all necessary benefits (33). Red light is on the visible spectrum, while infrared is divided into three categories which include: IR-A (760 – 1,400 nm), IR-B (1,400 – 3,000 nm), and IR-C (3,000 nm-1 mm) (4).

Red light commonly penetrates the body to a depth less than 10 mm (37). Within this range, red light therapy is readily absorbed by blood and skin surface components but is limited in tissue penetration (37). On the other hand, NIR light is not absorbed as easily, which gives it a much greater depth of tissue penetration (>30 – 40 mm) (37). This increases photon deposition in the wound bed, thereby improving therapeutic healing efficacy (37). It is crucial to note that PBM does not reach a point of ultraviolet (UV) radiation, which has been shown to be a possible mutagen and non-specific damaging agent when overexposed (6).

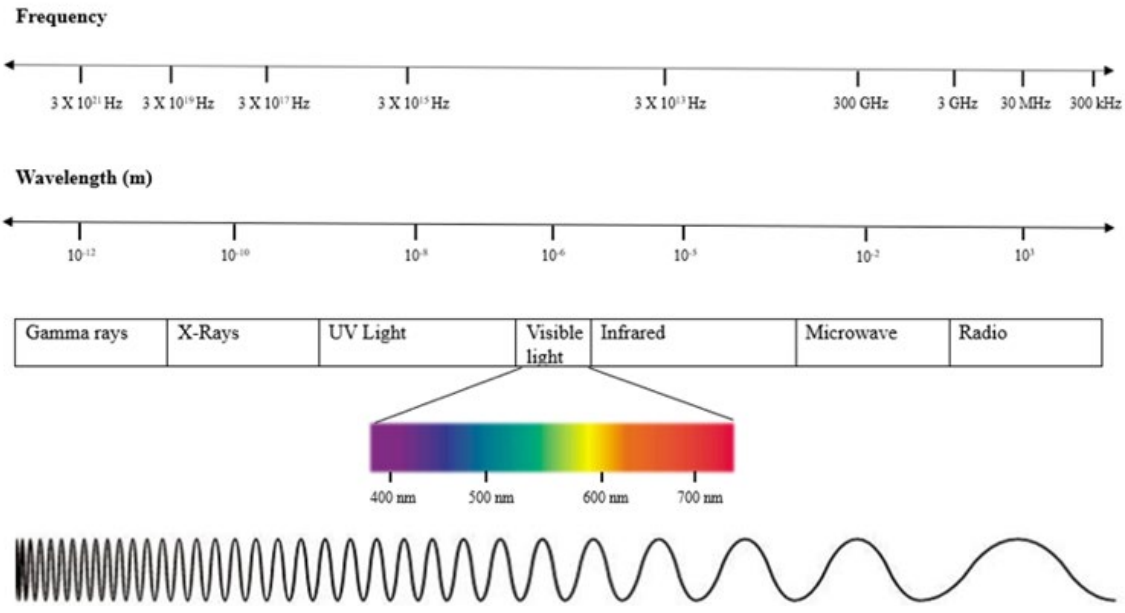


FIGURE 1. ELECTROMAGNETIC SPECTRUM AND WAVELENGTHS

DEVELOPMENTS IN LIGHT-EMITTING DIODE TECHNOLOGY

Initially, light-emitting diodes (LEDs) only emitted red light, but further advancements in LED technology have given access to various wavelength contents ranging from UV to infrared, which also means it holds great controllability in tuning brightness, pulse durations, and spectra (11). This is of prominence because these exact parameters are the specifications necessary for PBM applications in light therapies (11). Conventional PBM devices utilize expensive lasers, but LED technology is an option that is more affordable and can be easily incorporated into an array to treat much larger surfaces, which is more convenient for full-body treatments (11). Furthermore, dose control and irradiation time when using PBM are vital since either too low or too high amounts could lead to the problem of the treatment losing its effectiveness (11). That being the case, the precise control that LED light sources afford is a great way to prevent this issue from occurring and ensure the success of PBM (11).

PBM EXPERIMENTS

In 1993, the National Aeronautics and Space Administration (NASA) decided to do a PBM experiment to study plant growth in space; however, in doing so, it was discovered that delivering light deep into the tissues of the body could have an application in stimulating wound healing and human tissue growth (5,36). Subsequently, further research concluded that red light therapy could be a way to help improve the medical care afforded to astronauts on long-term space missions where health risks due to changes in gravity are of grave concern (36). In the past, injuries that astronauts acquired during their time in space, such as muscle and bone atrophy, were not treated until they returned to Earth (36). To remedy this, it was suggested that an LED blanket device could be utilized while in space to prevent muscle atrophy through the process of near-infrared light stimulating energy metabolism in the muscle, bone, skin, and subcutaneous tissue (36). These findings and novel applications of PBM by NASA pioneered the way for future research in the field of light therapy.

MODERN APPLICATION OF PBM THERAPY IN ATHLETICS

PBM therapy has gained wide commercial success via an increasing availability of devices, with some being designed for a myriad of clinical settings and others for direct consumer use (19). Due in part to this rising recognition by both the public and medical field, PBM therapy treatment is more frequently being employed in strength and conditioning to improve strength gains, boost endurance, increase fatigue resistance, and more (8,16,26).

PBM THERAPY AT THE MOLECULAR LEVEL

The most discussed hypothesis behind the underlying mechanism of light therapy revolves around a chromophore (a molecule that can absorb light) within the mitochondria called cytochrome c oxidase (CCO), which is part of the respiratory chain and is responsible for the final reduction of oxygen into water (9,20). It is theorized that CCO enzyme activity is inhibited by nitric oxide (NO); however, when CCO absorbs the photons from red light, NO is dissociated, leading to an improvement in ATP production, electron transport, oxygen consumption, glucose metabolization, and mitochondrial membrane potential (9,20).

Another hypothesis states that light-sensitive ion channels are activated by PBM, which allows calcium (Ca^{2+}) to enter the cell (9,20). After these events occur, several signaling pathways that lead to the activation of transcription factors are triggered through an increase in reactive oxygen species, cyclic adenosine monophosphate, NO, and Ca^{2+} (9,20). The activation of transcription factors contributes to protein production, cell migration and proliferation (a factor in wound healing and bone formation), anti-inflammatory signaling, anti-apoptotic proteins (which protect cells at risk of dying), and antioxidant enzymes (3,7,9,20). These theorized molecular changes in the mitochondria are vital as they are the most likely explanation as to why light therapy shows positive effects (either as pre-conditioning or post-exercise recovery) within athletic performance, muscle recovery, brain function, repair/pain of nerves, healing of bones, tendons, and wounds (9,15).

PBM THERAPY TO IMPROVE INFLAMMATION

One of the most explored and verifiable applications of PBM therapy is the overall reduction of inflammation (21). PBM therapy primarily influences the process of inflammation by lowering levels of pro-inflammatory cytokines (increases inflammation) and boosting the expression of anti-inflammatory cytokines (reduces inflammation) (28).

Research investigating how injured university athletes could be helped to return to play as quickly as possible and in the best of conditions found that PBM therapy could play a significant role in reducing inflammation, pain, and promoting repair in acute sports-related injuries (17). In this study, the effect of PBM therapy on a total of 395 injuries in 65 male and female student-athletes participating in sports such as baseball, basketball, cross country, soccer, and football were studied for 15 months (17). In order of most frequent, these were the following reported injuries: knee sprains, hamstring sprains, Achilles tendonitis, intercostal sprains, shoulder sprains, abdominal strains, and fractures of the foot (17). Visual analogue scale (VAS) was used to assess pain levels and the actual date of return to play (RTP) (17). Most student-athletes reported a reduction in inflammation and pain with no negative side effects or increase in pain during treatment sessions (17). Of note is that subjects with hamstring strain and knee strain injuries took the longest to report lower pain levels than what they had initially started with compared to those with ankle sprain injuries (17).

Some of the earliest published human PBM studies aimed to determine how PBM therapy could affect delayed onset muscle soreness (DOMS) (13). In one study, a randomized double-blind controlled study worked with 27 subjects between the ages of 18 – 35 years, which were put into three groups (12). The experimental group received PBM therapy for a period of five

days at three standardized sites over the musculotendinous junction of the biceps while the sham group received the same treatment with a dummy device (12). The control group did not receive any treatment (12). Assessments used to track any effects were measured using the VAS and McGill pain questionnaire, resting angle (RANG), and girth measurements (12). Researchers concluded that those who were irradiated with PBM displayed a significant decrease in pain associated with DOMS, as well as overall pain scores compared to the control and sham groups (12). The authors also suggested that PBM therapy could be a beneficial method to relieve DOMS, especially after doing an exercise for the first time (12).

PBM THERAPY AND ITS EFFECT ON MUSCLE

The use of PBM therapy to reduce muscle damage was first explored in animal models by irradiating the muscles before an intense session of exercise and then studying the extent of muscle damage by looking at CK levels (14). These studies in animals, particularly rats, were the precursor to clinical trials in humans (14). Throughout the years, numerous studies exploring the effect of PBM therapy on muscles have found that it can reduce muscle damage, enhance muscular performance, promote resistance to muscle fatigue, quicken recovery, and possibly play an important role in strength training as muscular pre- and post-conditioning (16,30,31,38).

Knowing that PBM therapy can reduce oxidative stress and inflammatory responses in muscle tissue, researchers examined how it would act upon biceps muscle performance, fatigue development, and post-exercise recovery (24). To conduct their research, they gathered nine healthy volleyball players placed into two groups (24). One group received 30 s of irradiation targeting the biceps over their non-dominant arm, while the other group obtained a placebo treatment three minutes before beginning to exercise (24). Both groups then performed a voluntary elbow flexion repetition with 75% maximal voluntary contraction force until failure (24). It was concluded that pre-conditioning of the muscles with PBM therapy not only increased endurance for repeated elbow flexion against resistance, but also decreased post-exercise levels of blood lactate, CK, and C-reactive protein (24). Based on these findings, the author proposed that PBM therapy applied before exercise could be helpful not only in delaying fatigue but also in helping with recovery (24).

Another study targeted the subject of how PBM therapy could impact physical strength training compared to strength training alone (13). This investigation consisted of 36 healthy men around 20 years of age with varying physical activity training experience ranging from beginner to moderate (13). These subjects were placed into three groups: one doing strength training with PBM therapy, another doing strength training only, and a control group (13). The groups performing strength training did a leg-press exercise with a load equal to 80% of one-repetition maximum (1RM) over a period of 12 weeks (13). The quadriceps muscle on the lower limbs of subjects doing strength training with PBM therapy was irradiated after each exercise session (13). Muscle strength and volume were assessed using the 1RM leg press test, isokinetic dynamometer test to evaluate joint torque, and by measuring thigh perimetry (13,29). The authors found that those who performed strength training with PBM therapy as post-conditioning demonstrated a 55% increase in the 1RM leg press test and enhanced muscle performance in the isokinetic dynamometer test compared to the other groups (13).

PBM THERAPY FOR COGNITIVE FUNCTION AND MENTAL HEALTH

Cognitive dysfunction associated with sports-related traumatic brain injury (TBI) is of growing concern (27). In fact, an 11-year study found that the diagnosis of concussion in high school sports has increased every year by 16.5% (27). Unfortunately, rates of depression, anxiety, and psychological symptoms are also markedly elevated in TBI survivors (23). To combat this, research has found that PBM therapy can improve TBIs and depression when applied by transcranial means (10).

In one study, 11 chronic TBI patients with brain injuries caused by accidents ranging from motor vehicle accidents to sports-related incidents received 18 treatments with an LED-based device (27). Treatment was performed on various locations of the scalp with a 10-min duration of light therapy on each area (27). Testing was performed before and after transcranial LED, culminating in improvements in sleep, executive function, verbal memory, as well as fewer post-traumatic stress disorder (PTSD) and depression symptoms (27). These results were possible because PBM therapy enhances ATP synthesis, which increases regional cerebral blood flow due to the release of NO and is vital in allowing a faster repair of the affected nervous system (10,27).

Other research was similarly able to corroborate that PBM therapy may be able to reduce the severity of depression, anxiety, headaches, and insomnia (22,32). It can be inferred from these studies that PBM therapy may be able to improve the overall brain function of athletes, specifically those who suffer from psycho-emotional stress due to being in a competitive environment, which may put them at greater risk for chronic fatigue syndrome, failure in physical training, and predisposition to muscle damage (2,32).

PBM THERAPY EFFECTS ON SLEEP QUALITY AND ENDURANCE

A study seeking to help athletes perform at their best was able to confirm that PBM therapy, which was termed “a noninvasive and nonpharmacologic therapy,” has a positive influence on the sleep quality of athletes (38). This study followed 20 female basketball players in China who were separated into two groups (38). The first 10 athletes received PBM therapy and the other 10 went through a placebo (38). Athletes in the PBM therapy group were exposed to this treatment with an instrument for 30 min every night for a span of 14 days while the placebo group was separated from this exposure (38). To measure the outcomes, a Pittsburgh sleep quality index (PSQI) questionnaire, serum melatonin, and a 12-min run were completed during pre-intervention as well as post-intervention (38). After 14 days, the group of athletes

exposed to PBM therapy showed an improvement in sleep, serum melatonin level, and endurance performance (38). The authors also suggested that PBM therapy could be a way to help prevent sleep disorders after training and improve the overall daily functioning of athletes (38).

There was an additional study conducted to figure out the best moment that PBM therapy could be applied in association with an endurance training program (26). To accomplish this, researchers gathered 77 healthy volunteers who were tasked with completing a 12-week endurance program using a treadmill training protocol (26). These volunteers were randomly allocated to four separate groups using various combinations of PBM therapy and/or placebo before and after each training session (26). Seventeen sites on each lower limb were irradiated with PBM three times per week (26). Assessments measuring time until exhaustion, oxygen uptake, and body fat were executed before the start of the training protocol as well as at the 4th, 8th, and 12th week (26). The researchers were able to conclude that compared to the group treated with a placebo before and after, PBM applied before and after aerobic endurance training sessions substantially improved endurance and oxygen uptake as well as decreased body fat percentages (26).

PBM DEVICES IN THE TRAINING ROOM

There is a variety of PBM equipment available for use in the training room that can be employed depending on the sport, injury, and results desired. These devices range from handheld devices, stand-up panels, and whole-body PBM beds. Most research on athletes and PBM therapy has been carried out with handheld devices due to their low cost and ability to target localized muscle tissue (18). Since handheld devices are small and portable, they are also beneficial if treatment needs to be applied on a particular body part or for traveling purposes. An example of how handheld devices can be utilized is a cyclist getting light therapy on the quadriceps, gluteus, hamstrings, and calf muscles to enhance lower body performance (18,34).

Compared to handheld devices, stand-up panels and whole-body PBM beds have been researched less due to their high cost, but they do have multiple advantages (18). One benefit of larger devices is that the administration of therapy does not require another person to apply the treatment (18). This means that an athlete scheduled to do full-body PBM treatment can arrive in the training room and self-administer the light therapy, which is an incentive for those who would prefer some privacy (18). In addition, it is relevant to consider that some athletes using larger equipment may feel discomfort due to the warmth of the panels and treatment room, so the implementation of small fans is suggested (18). One example of previous research successfully utilizing whole-body PBM beds consisted of studying the impact of red light therapy to improve the sleep of basketball athletes (18,38).

PBM THERAPY: A HOW-TO GUIDE

PBM therapy consists of red and infrared light, which is non-thermal (meaning it does not generate a significant amount of heat); although, some may experience a slight warming sensation on the skin during therapy (37). This is unique to each user based on the PBM panel being used, the wavelength of light, and individuality in chemical body reactions (1). The success of PBM therapeutic outcomes depends on the selection of optimal treatment protocols, which include not only the proper illumination parameters but also producing a consistent treatment schedule (1). When undergoing PBM therapy, users have the option to use eyewear protection, even though there are studies currently being performed to find the reliability of PBM as a possible treatment for eyesight issues and others that have shown that PBM therapy is relatively safe for vision (1,19). To obtain the best effects, the subject(s) should wear as minimal clothing as is comfortable (25).

The current protocol for healthy subjects is the following:

1. The dose should be 20 – 60 J for small muscle groups and 60 – 300 J for large muscle groups (25).
2. As for power, 50 – 200 mW per diode for single probes and 10 – 35 mW per diode for cluster probes is sufficient (25).
3. Wavelengths are usually between 640 nm (red) – 950 nm (infrared) as most studies combine red and infrared wavelengths concurrently (25).
4. The mode can be either pulsed or continuous (25).
5. It is recommended that for acute effects the subject be exposed to PBM 5 min – 6 hr before activity or training (25).
6. To derive chronic effects linked with strength training the subject must receive PBM therapy as pre-conditioning 5 – 10 min before each session (25).
7. For chronic effects associated with aerobic endurance, it is reported that irradiation should be performed at least 5 – 10 min before and after each training session (25).
8. The length of exposure to PBM should last around 30 s with the irradiation covering as much area as possible to more effectively stimulate the muscle groups involved in a certain activity (25).

FIGURE 2. PBM PROTECTIVE GLASSES

THE FUTURE OF PBM

Studies in diverse subjects ranging from exercise physiology, military (photomedicine) neurology, oncology, psychiatry, and more have examined PBM therapy based on its potential applications, safety, and functionality. Due to this rise in interest, one recent major advancement in PBM therapy has been the increasing ease of access to it. Previously, it was only available in certain places, such as exclusive spas or medical settings, but it is now available for commercial use and is likely to continue expanding (19). Another effect of the increasing usage of PBM is a growing worry that groups such as the International Olympic Committee and the World Anti-Doping Agency could potentially ban it in athletic competitions; although, this is highly unlikely because its intensity is similar to sunlight and there is no forensic test for light exposure (21). Organizations in the United States who are new to PBM and want to acquire a device for their athletes might be concerned as to how they would fare when confronted with FDA regulations. PBM devices, especially those utilizing LEDs, work at power levels under those that are currently deemed by the FDA to not be a medical risk, thus they have not been subject to therapeutic device regulation (21).

FIGURE 3. FLEXIBLE GOGGLES

CONCLUSION

This article focused on the evolution of red light therapy from its early beginnings to contemporary use. Red light therapy has undergone advancements and is now acknowledged for its anti-inflammatory properties and its ability to improve athletic performance and recovery. PBM stimulates the activity of mitochondria, leading to an increase in the production of adenosine triphosphate (ATP) for muscle function. It is effective in preventing muscle damage and fatigue, promoting better sleep and recovery, enhancing skeletal muscle performance, and protecting against muscle tissue damage. PBM holds great potential as a valuable resource for strength and conditioning coaches. There are infinite research possibilities that suggest further investigations for its different beneficial properties, for example, anti-inflammatory improvements when comparing healing outcomes for various types of injuries, different levels of fractures, and even everyday functionalities.

REFERENCES

1. Ablon, G. Phototherapy with light emitting diodes: Treating a broad range of medical and aesthetic conditions in dermatology. *The Journal of Clinical and Aesthetic Dermatology* 11(2): 21–27, 2018.

2. Ailioaie, LM, and Litscher, G. Photobiomodulation and sports: Results of a narrative review. *Life (Basel, Switzerland)* 11(12): 1339, 2021.

3. Ammann, KR, DeCook, KJ, Li, M, and Slepian, MJ. Migration versus proliferation as contributor to in vitro wound healing of vascular endothelial and smooth muscle cells. *Experimental Cell Research* 376(1): 58-66, 2019.

4. Barolet, D, Christiaens, F, and Hamblin, MR. Infrared and skin: Friend or foe. *Journal of Photochemistry and Photobiology B: Biology* 155: 78-85, 2016.

5. Cotler, HB. A NASA discovery has current applications in orthopaedics. *Current Orthopaedic Practice* 26(1): 72-74, 2015.

6. D'Orazio, J, Jarrett, S, Amaro-Ortiz, A, and Scott, T. UV radiation and the skin. *International Journal of Molecular Sciences* 14(6): 12222–12248, 2013.

7. da Silva, TG, Ribeiro, RS, Mencalha, AL, and de Souza Fonseca, A. Photobiomodulation at molecular, cellular, and systemic levels. *Lasers in Medical Science* 38(1): 136, 2023.

8. de Brito Vieira, WH, Bezerra, RM, Queiroz, RA, Maciel, NF, Parizotto, NA, and Ferraresi, C. Use of low-level laser therapy (808 nm) to muscle fatigue resistance: A randomized double-blind crossover trial. *Photomedicine and Laser Surgery* 32(12): 678-685, 2014.

9. de Freitas, LF, and Hamblin, MR. Proposed mechanisms of photobiomodulation or low-level light therapy. *IEEE Journal of Selected Topics in Quantum Electronics: A Publication of the IEEE Lasers and Electro-optics Society* 22(3): 7000417, 2016.

10. Dompe, C, Moncrieff, L, Matys, J, Grzech-Leśniak, K, Kocherova, I, Bryja, A, et al. Photobiomodulation-underlying mechanism and clinical applications. *Journal of Clinical Medicine* 9(6): 1724, 2020.

11. Dong, J, and Xiong, D. Applications of light emitting diodes in health care. *Annals of Biomedical Engineering* 45(11): 2509-2523, 2017.

12. Douris, P, Southard, V, Ferrigi, R, Grauer, J, Katz, D, Nascimento, C, and Podbielski, P. Effect of phototherapy on delayed onset muscle soreness. *Photomedicine and Laser Surgery* 24(3): 377-382, 2006.

13. Ferraresi, C, de Brito Oliveira, T, de Oliveira Zafalon, L, de Menezes Reiff, RB, Baldissera, V, de Andrade Perez, SE, et al. Effects of low level laser therapy (808 nm) on physical strength training in humans. *Lasers in Medical Science* 26(3): 349-358, 2011.

14. Ferraresi, C, Huang, YY, and Hamblin, MR. Photobiomodulation in human muscle tissue: An advantage in sports performance? *Journal of Biophotonics* 9(11-12): 1273-1299, 2016.

15. Ferraresi, C, Kaippert, B, Avci, P, Huang, YY, de Sousa, MV, Bagnato, VS, et al. Low-level laser (light) therapy increases mitochondrial membrane potential and ATP synthesis in C2C12 myotubes with a peak response at 3-6 h. *Photochemistry and Photobiology* 91(2): 411-416, 2015.

16. Ferraresi, C, Oliveira, T, Zafalon, L, Reiff, RB, Baldissera, V, Perez, S, et al. Effects of low level laser therapy (808 nm) on physical strength training in humans. *Lasers in Medical Science* 26(3): 349-358, 2010.

17. Foley, J, Vasily, DB, Bradle, J, Rudio, C, and Calderhead, RG. 830 nm light-emitting diode (led) phototherapy significantly reduced return-to-play in injured university athletes: A pilot study. *Laser Therapy* 25(1): 35-42, 2016.

18. Ghigiarelli, JJ, Fulop, AM, Burke, AA, Ferrara, AJ, Sell, KM, Gonzalez, AM, et al. The effects of whole-body photobiomodulation light-bed therapy on creatine kinase and salivary interleukin-6 in a sample of trained males: A randomized, crossover study. *Frontiers in Sports and Active Living* 29(2): 48, 2020.

19. Glass, GE. Photobiomodulation: The clinical applications of low-level light therapy. *Aesthetic Surgery Journal* 41(6): 723-738, 2021.

20. Hamblin, MR. Shining light on the head: Photobiomodulation for brain disorders. *BBA Clinical* 6: 113-124, 2016.

21. Hamblin MR. Mechanisms and applications of the anti-inflammatory effects of photobiomodulation. *AIMS Biophysics* 4(3): 337-361, 2017.

22. Henderson, TA, and Morries, LD. SPECT perfusion imaging demonstrates improvement of traumatic brain injury with transcranial near-infrared laser phototherapy. *Advances in Mind-Body Medicine* 29(4): 27-33, 2015.

23. Hipskind, SG, Grover, FL, Jr, Fort, TR, Helffenstein, D, Burke, TJ, Quint, SA, et al. Pulsed transcranial red/near-infrared light therapy using light-emitting diodes improves cerebral blood flow and cognitive function in veterans with chronic traumatic brain injury: A case series. Published ahead of print. *Photomedicine and Laser Surgery*, 2018.

24. Leal Junior, EC, Lopes-Martins, RA, Frigo, L, De Marchi, T, Rossi, RP, de Godoi, V, et al. Effects of low-level laser therapy (LLLT) in the development of exercise-induced skeletal muscle fatigue and changes in biochemical markers related to postexercise recovery. *The Journal of Orthopaedic and Sports Physical Therapy* 40(8): 524-532, 2010.

25. Leal-Junior, ECP, Lopes-Martins, RÁB, and Bjordal, JM. Clinical and scientific recommendations for the use of photobiomodulation therapy in exercise performance enhancement and post-exercise recovery: Current evidence and Future Directions. *Brazilian Journal of Physical Therapy* 23(1): 71-75, 2018.

26. Miranda, EF, Tomazoni, SS, de Paiva, P, Pinto, HD, Smith, D, Santos, LA, et al. When is the best moment to apply photobiomodulation therapy (PBMT) when associated to a treadmill endurance-training program? A randomized, triple-blinded, placebo-controlled clinical trial. *Lasers in Medical Science* 33(4): 719-727, 2018.

27. Naeser, MA, Zafonte, R, Krengel, MH, Martin, PI, Frazier, J, Hamblin, MR, et al. Significant improvements in cognitive performance post-transcranial, red/near-infrared light-emitting diode treatments in chronic, mild traumatic brain injury: Open-protocol study. *Journal of Neurotrauma* 31(11): 1008-1017, 2014.

28. Neves, LMS, Gonçalves, ECD, Cavalli, J, Vieira, G, Laurindo, LR, Simões, RR, et al. Photobiomodulation therapy improves acute inflammatory response in mice: The role of cannabinoid receptors/ATP-sensitive K+ channel/p38-MAPK signalling pathway. *Molecular Neurobiology* 55(7): 5580-5593, 2018.

29. Parrington, L, and Ball, KA. Biomechanical considerations of laterality in sport. *Laterality in Sports* 279-308, 2016.

30. Roose, J, de Vries, WR, Schmikli, SL, Backx, FJG, and van Doornen, LJP. Evaluation and opportunities in overtraining approaches. *Research Quarterly for Exercise and Sport* 80(4): 756-764, 2009.

31. Santos, LA, Marcos, RL, Tomazoni, SS, Vanin, AA, Antonialli, FC, Grandinetti Vdos, S, et al. Effects of pre-irradiation of low-level laser therapy with different doses and wavelengths in skeletal muscle performance, fatigue, and skeletal muscle damage induced by tetanic contractions in rats. *Lasers in Medical Science* 29(5): 1617-1626, 2014.

32. Schiffer, F, Johnston, AL, Ravichandran, C, Polcari, A, Teicher, MH, Webb, RH, and Hamblin, MR. Psychological benefits 2 and 4 weeks after a single treatment with near infrared light to the forehead: A pilot study of 10 patients with major depression and anxiety. *Behavioral and Brain Functions* 5: 56, 2009.

33. Serrage, H, Heiskanen, V, Palin, WM, Cooper, PR, Milward, MR, Hadis, M, and Hamblin, MR. Under the spotlight: mechanisms of PBM concentrating on blue and green light. *Photochemical and Photobiological Sciences: Official Journal of the European Photochemistry Association and the European Society for Photobiology* 18(8): 1877-1909, 2019.

34. Teles, MC, Fonseca, IAT, Martins, JB, de Carvalho, MM, Xavier, M, Costa, SJ, et al. Comparison between whole-body vibration, vight-emitting diode, and cycling warm-up on high-intensity physical performance during sprint bicycle exercise. *Journal of Strength and Conditioning Research* 29(6): 1542-1550, 2015.

35. Wayne, K. What are electromagnetic waves? *Electromagnetic Waves and Lasers 2nd Edition* Bellevue, WA: IOP Publishing Ltd; 2020.

36. Whelan, HT, Buchmann, EV, Whelan, NT, Turner, SG, Cevenini, V, Stinson, H, et al. NASA light emitting diode medical applications from deep space to deep sea. School of Dentistry Faculty Research and Publications. 2001. Retrieved 2023 from https://epublications.marquette.edu/dentistry_fac/243.

37. Yadav, A, and Gupta, A. Noninvasive red and near-infrared wavelength-induced photobiomodulation: Promoting impaired cutaneous wound healing. *Photodermatology, Photoimmunology, and Photomedicine* 33: 4-13, 2017.

38. Zhao, J, Tian, Y, Nie, J, Xu, J, and Liu, D. Red light and the sleep quality and endurance performance of Chinese female basketball players. *Journal of Athletic Training* 47(6): 673-678, 2012.

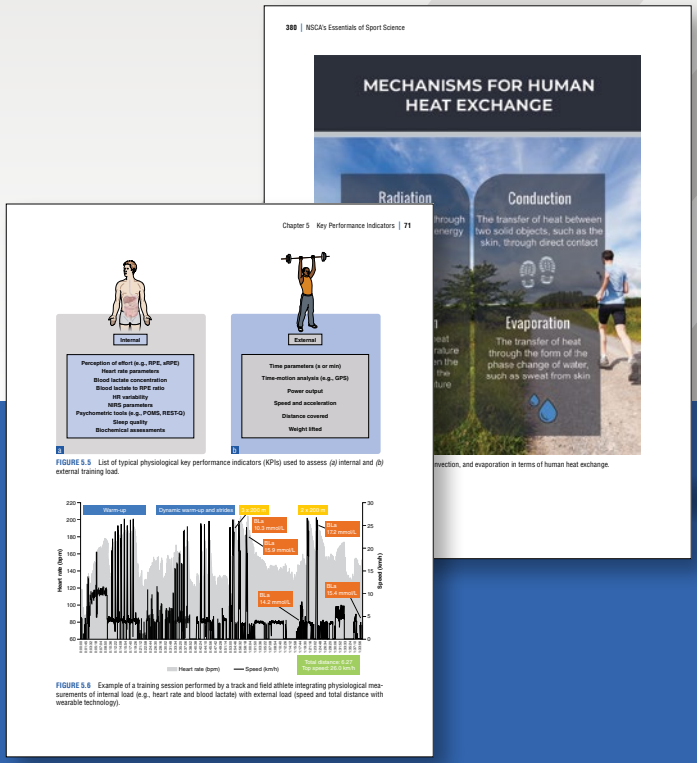
ABOUT THE AUTHORS

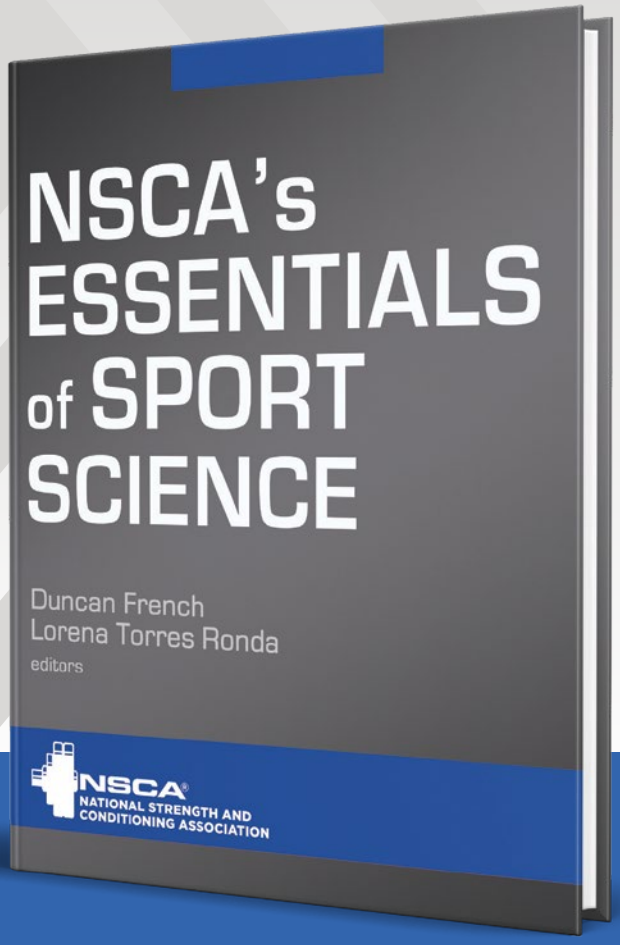
Juan Gonzalez is an Associate Professor within the Department of Health and Human Performance and the College of Health Professions at the University of Texas Rio Grande Valley. He is an Applied Exercise Physiologist and uses redlight therapy in conjunction with National Collegiate Athletic Association (NCAA) strength and conditioning programs for Division I female volleyball players. Gonzalez is also very active in the running community with the uses of red and infrared light therapy. His line of research currently is on the effects of red and infrared light therapy in Division I female athletes. He is also a member of the Association of Pulse Magnetic Fields Professionals (AOPP) and is certified in the use of redlight therapy.

Yuliana Sanchez-Trinidad is a prospective fall 2024 graduate in Exercise Science with a concentration in Pre-Occupational Therapy within the Department of Health and Human Performance at the College of Health Professions at the University of Texas at Rio Grande Valley (UTRGV) in Edinburg, TX. She is currently working on researching photobiomodulation therapy use on athletes with Dr. Juan Gonzalez. She is part of the Health and Kinesiology Club as well as the Special Olympics Inclusion College Club at UTRGV, where she has had the opportunity to give back to her community and learn about disability. Sanchez-Trinidad plans on earning a doctorate in occupational therapy (OTD) degree. Her interest includes researching how to further occupational therapy treatment for burn victims.

Keyla Olmeda was a May 2023 graduate in Exercise Science with a concentration in Pre-Physical Therapy within the Department of Health and Human Performance at the College of Health Professions at the University of Texas Rio Grande Valley in Edinburg, TX. Additionally, she earned a certification in basic nutrition and basic sports nutrition. She plans on applying to physical therapy school and working within the pediatrics field.

PREPARE WITH CONFIDENCE FOR THE NSCA'S CPSS® EXAM





ORDER YOUR COPY TODAY »
at NSCA.com

NSCA® | HUMAN KINETICS

MATRIX

MAGNUM MX RACKS

STRENGTH WITHOUT LIMITS

Design a training area that helps athletes put in more work in less time with Magnum MX Racks. The configurable design and 70 attachment options allow for virtually endless storage and training components — all built to last in the most intense training environments.

Discover how you can build the ultimate rack for your team at matrixfitness.com.

matrixfitnessusa | matrixfitness.com | 866.693.4863

SORINEX®
EXERCISE EQUIPMENT

BE LEGENDARY™

WWW.SORINEX.COM