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Phototherapy and Grip Muscle Performance

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Abstract

Background: Grip strength and endurance has been shown to be an overall indicator of physical strength, function, and health. Previous research has provided evidence that phototherapy may increase muscle endurance. The purpose of this study was to investigate the effects of red/infrared light and blue/infrared light on grip endurance, lactic acid accumulation, and delayed onset muscle soreness (DOMS).

Materials and Methods: Fourteen subjects, seven men, and seven women (mean age 23.2 ± 1.7) took part in this randomized crossover double-blinded study. The subjects received either phototherapy (red/infrared probe with 4 red light emitting diodes (LEDs); λ= 670nm; 5 infrared laser diodes; λ= 850nm; 540mW power output; 65 seconds of irradiation, applied in 3 locations over the forearm and hand of the dominant arm; 35.1 J of total energy per site), phototherapy (blue/infrared probe with 28 blue LEDs emitting λ= 405nm; 8 infrared LEDs emitting λ= 880nm; 500mW of power output; 80 seconds, applied to the same points for a 40.0 J total energy per site) or placebo phototherapy using an identical cluster probe. The dosage in energy density units for the phototherapy treatments were 8 J/cm^2 per site. Each intervention was applied immediately before performance of the grip endurance exercise.

All subjects performed voluntary grip strength repetitions until they reached 50% of their initial maximal voluntary contraction. The number of repetitions performed was utilized for data analysis. Lactic acid (La) accumulation was measured five minutes after the exercise has been completed. A visual pain analog scale measured DOMS at 24 and 48 hours post exercise.

Results: There were no significant differences between any of the three conditions on muscle endurance, La accumulation and pain scores as analyzed by Repeated Measures ANOVA.

Conclusion: The application of a standard therapeutic dosage of phototherapy did not improve grip endurance.

Keywords: Grip endurance; Lactate; DOMS

Introduction

Phototherapy is currently used to treat a variety of musculoskeletal conditions. Recent meta-analyses performed by Fulop et al. [1,2] have provided evidence for the clinical usage of phototherapy for pain and tissue repair. Phototherapy has also been shown to decrease the onset of delayed onset of muscle soreness (DOMS) after exercise [3]. Recently, Baroni et al. [4] and Leal Junior et al. [5-10] have investigated the effects of phototherapy on muscle endurance and recovery in athletes.

The attenuation of muscle fatigue with phototherapy is a new topic in the field of physical therapy. The application of red and infrared diodes with a dosage 25.1 joules (J) over three areas on the quadriceps resulted in higher torque produced by the knee extensors following 30 maximal concentric knee extension and flexion contractions as compared to a placebo treatment [4]. However, performance in the lower body Wingate test was not enhanced following phototherapy application [7,9]. Their results may have been due to the multijoint nature of the Wingate test and the application of phototherapy only to the quadriceps. However, post exercise creatine kinase and lactate were decreased suggesting that phototherapy may benefit post exercise recovery [9]. Leal Junior and associates [5,6,8,10] have investigated in four similar randomized double blind placebo controlled studies, the effects of phototherapy on improving elbow flexion muscle endurance with professional volleyball players utilizing various phototherapy devices from laser diodes to light emitting diodes with wavelengths from 655 to 850 nm delivering from 5 to 41.7 J per application site. The results of all four studies were that a significantly greater number of repetitions were performed by the elbow flexors under the phototherapy conditions resulting in increased muscle endurance.

The previous studies were successful with single joint actions utilizing the elbow flexors and lower extremities as the exercise with concentric contractions [4-6,8,10]. Phototherapy applied to multi joint activities such as the Wingate test did not improve performance [7,9]. However, De Marchi et al. [11] demonstrated that phototherapy applied before a progressive intensity running protocol resulted in a significant improvement in time to exhaustion and $VO_{2\ max}$ although the effect size was small. The effect of phototherapy on an isometric contraction has been investigated by de Almeida and associates [12]. They concluded that phototherapy delivered by red or infrared diodes as compared to a placebo with a total dosage of 20 J increased peak force and average force by the elbow flexors of the non-dominant hand over a 60 second contraction.

The physiological mechanisms proposed to explain the improvements in muscle endurance and recovery are based on the photochemical effects of phototherapy. The photochemical effects provide additional cellular adenosine triphosphate (ATP), which provides additional energy to perform mechanical work and it allows the inflammation process to start earlier, thus fostering tissue healing, and pain management [1]. Red light (660 nm) and infrared (880 nm) wave-

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lengths have been shown to increase electron transfer, which leads to an increase in mitochondrial respiration and ATP synthesis [1,2,5]. Greater amounts of ATP should carryover and lead to enhanced muscle performance. Blue light (405 nm), on the other hand, may increase performance by changing the redox state of the cell, thus improving muscular contraction [13]. These physiological effects provide the rationale for investigating the effects of phototherapy on muscle performance. The concentration of blood lactate, a glycolytic muscle metabolism by-product, can also be an important factor related to the development of muscle fatigue and thus muscle performance [5-10].

Previous research has only investigated the effects of red and infrared phototherapy on muscle performance. The effects of blue light on muscle performance are not known. Grip strength and grip endurance is the result of numerous joint and muscles and involves an isometric contraction. Grip strength and endurance has been shown to be an overall indicator of physical strength, function, and health [14,15]. Because grip is critical to many daily, sport, and recreational activities, utilizing grip endurance should provide more practical and useful information on this topic. The effects of phototherapy on grip endurance have not been previously investigated. The purpose of our study was to investigate the effects of red/infrared, and blue light/infrared on grip endurance, lactate accumulation, and DOMS.

Materials and Methods

The design of this investigation was a double blind randomized crossover placebo-controlled trial. The Institutional review board at New York Institute of Technology (NYIT) in Old Westbury, New York, approved the study. Fourteen subjects, seven men, and seven women (mean age 23.2±1.7) took part in this study. Subjects' physical characteristics are presented in Table 1. Subjects were recruited from the New York Institute of Technology community. None of the subjects were elite or competitive athletes. They were average physically active full time college-aged students. The subjects were screened for inclusion and exclusion criteria by a health questionnaire that was approved the New York Institute of Technology Institutional Review Board. An informed consent form was provided to and signed by the subjects before starting the study.

Randomization

All subjects were treated with the two phototherapy treatments and placebo on three separate occasions followed by a grip endurance test. The treatment conditions were randomized with a Latin square design, which determined whether the order in which the subject received red/infrared, blue/infrared or placebo condition. All subjects received all three treatment conditions over the course of the study. The order for the treatments was relayed to the technician operating the phototherapy equipment, which was concealed from the subjects and the research team collecting the data. Testing took place over a two-week period. Each condition was separated by one week. All testing occurred between 12:30 and 2:00 PM.

Inclusion criteria

Inclusion criteria included: All subjects were in good overall health that exercised at least two days per week and were between the ages of 18-35 years old.

Characteristics	
Age (years)	23.2 ± 1.7
Height (cm)	169.5 ± 9.1
Weight (kg)	71.2 ± 14.1

*Values are given as mean ± *SD*

Table 1: Physical Characteristics of Subjects (n=14)*

Exclusion criteria

Exclusion Criteria included: any cardiopulmonary condition, any major musculoskeletal injuries over the last six months of the dominant upper extremity, any health issues that would interfere with a subject's safety during exercise or any photosensitivity. A medical history was taken from all subjects to evaluate for the presence of any exclusion criteria.

Procedures

Subjects were first instructed on the proper use of a grip strength dynamometer. The Jamar hand dynamometer (Sammons Preston, Bolington, IL.) was utilized for the study. The Jamar dynamometer is the standard for measuring grip strength according to the American Society of Hand Therapy [16]. Following instructions the subjects demonstrated the proper use of the dynamometer. The subjects were seated with the elbow of their dominant upper extremity flexed to 90-degrees and their shoulder and wrist maintained in neutral. The subjects then performed a maximal contraction for three seconds with the dynamometer three times, with a 30 second rest period in between trials, in order to measure their maximum grip strength. Their highest result was recorded as their one repetition maximal grip strength (1RM). A similar protocol has been previously described [17]. After recording their 1 RM the subjects were sent to receive phototherapy treatment (red/infrared, blue/infrared light, or placebo) behind a portable curtain, which blinded the testers from knowing the treatment given to the subjects. The dosage in energy density units for the phototherapy treatments were 8 J/cm^2 per site. This is considered within a standard therapeutic dose according to Cameron [18]. The phototherapy unit for the red/infrared light was the Vectra Genisys (Chattanooga Group, Hixson, TN). The red/infrared unit has four red light emitting diodes producing a 670 nm wavelength and five laser diodes emitting an 850 nm wavelength. The phototherapy machine utilized for the blue/ infrared light was the Solaris Phototherapy Unit manufactured by Dynatronics (Salt Lake City, UT). The blue/infrared probe has twenty-eight blue light emitting diodes producing a 405 nm wavelength and eight infrared light emitting diodes producing a 880 nm wavelength. Table 2 and 3 display the parameters for the two units. The phototherapy was applied to three different sites: the muscle bellies of the common flexor and common extensor tendons and to the thenar eminence. Grip force is produced by the co-contraction of wrist flexors and extensors and flexor pollicis brevis muscles [19,20]. The light probe was applied in contact mode with the cluster probe held at a 90-degree angle to the skin in each of the treatment sites. The placebo condition consisted of identical treatment times to the other two conditions without the machine turned on. The operator was instructed not to communicate the type of phototherapy given

Number of Diodes	4 red Light Emitting Diodes and 5 Infrared Laser Diodes
Wavelength	670nm for red and 850nm for infrared
Power output	540mW
Energy	35.1 J per point
Energy Density	8 J/cm^2 per point
Treatment Time	65 seconds per point
Number of irradiation points	3
Application mode	Phototherapy probe was applied in contact mode with the cluster head held at a 90 degree angle to the skin with slight pressure.

Table 2: Phototherapy Parameters for Red/Infrared Probe.

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Number of Diodes	28 blue Light Emitting Diodes and 8 infrared Light Emitting Diodes
Wavelength	405nm for blue and 880nm for infrared
Power output	500mW
Energy	40.0 J per point
Energy Density	8 J/cm^2 per point
Treatment Time	80 seconds per point
Number of irradiation points	3
Application mode	Phototherapy probe was applied in contact mode with the cluster head held at a 90 degree angle to the skin with slight pressure.

Table 3: Phototherapy Parameters for Blue/Infrared Probe.

with other testers in the room. The subjects wore headphones with jazz music playing and a blindfold during the treatment. Immediately following phototherapy application the subjects were seated in the position mentioned above and was instructed to perform maximal hand grip contractions on the grip dynamometer for a three second hold followed by a three second rest period. A metronome was also used as an audible timer. A tester was reading the gauge of the dynamometer and recorded how many repetitions until the subject reached 50% of their 1RM. The number of repetitions were recorded and utilized for subsequent data analysis.

Blood lactate concentrations were measured five minutes following the termination of the test of grip endurance. The period for measuring the highest lactate accumulation is between three to five minutes post exercise [21]. Lactate accumulation was measured using the Accutrend Lactate Portable Analyzer (Roche Diagnostics, Manheim, Germany). The Accutrend Lactate Portable Analyzer has been shown to be accurate and reliable [22]. A small amount of blood (20-25 micro liters) was collected from a finger prick on the dominant hand. Lactate was measured via enzymatic determination and reflectance photometry at 660-nm wavelength for 60 seconds. Lactate was measured in mmoles/liter. The lactate accumulated was recorded and utilized for subsequent data analysis.

DOMS was assessed by using the Visual Analogue Scale (VAS). This was previously utilized in another DOMS study by the author [3]. Following each treatment condition, each subject was asked to rate their highest level of pain over the previous 24 hour and 48 hour period by marking a graphic pain scale on a 100 mm line marked no pain on one end and maximal pain on the other. They were given VAS scales to take home and instructed to return them to the experimenters after filling them out. Pain was quantified by measuring the distance, to the nearest millimeter. Subjects were asked to refrain from applying any heat or cold pack or take any anti-inflammatory/pain medication for two days following exercise. The scores from the VAS were recorded and utilized for subsequent data analysis.

Statistical analysis

Statistical analyses were performed utilizing SPSS for Windows (version 15.0, Chicago, Ill.), using a repeated measures design. The independent variables were the three conditions: placebo, red/infrared phototherapy and blue/infrared phototherapy and the dependent variables were grip endurance, lactate accumulation and DOMS. Group means and standard deviations were calculated for all dependent variables. A priori sample size calculations revealed that nine subjects were required in each group to detect observed differences at a power of 80%. We performed repeated measures ANOVA for each dependent variable. An alpha level of $p<0.05$ was used for all statistical comparisons.

Results

The means and standard deviations of the number of repetitions performed, lactate accumulated and VAS scores at 24 and 48-hour post exercise for the fourteen subjects are presented in Table 4. The assumption of sphericity was tested using Mauchly's test and was not violated in any of the statistical procedures. A repeated measure ANOVA showed no significant differences for the number of repetitions performed ($F_{2,26}$=0.791, p=0.464). A repeated measure ANOVA showed no significant differences for the lactate accumulated ($F_{2,14}$= 0.392, p=0.683). A repeated measure ANOVA showed no significant differences for the 24-hour VAS scores ($F_{2,26}$=0.404, p=0.672). A repeated measure ANOVA showed no significant differences for the 48-hour VAS scores ($F_{2,26}$=1.325, p=0.283).

Discussion

This investigation examined the effects of red/infrared, and blue/infrared phototherapy and a placebo on grip endurance, lactate accumulation, and DOMS in healthy active young adults. The phototherapy procedures utilized in this study did not enhance grip endurance; alter the amount of lactate accumulated or DOMS produced when compared to a placebo. This was the first study to the author's knowledge to investigate handgrip endurance, a multi joint isometric contraction, as the outcome measure.

There was a minimal amount of lactate accumulated as a result of the handgrip endurance test. The range was between 2.36 and 2.58 mmoles/liter of lactate accumulated with no significant difference between any of the phototherapy and placebo conditions. These finding are in agreement with Leal Junior et al. [6,10] who reported there were no significant differences between phototherapy and a placebo on lactate accumulation from elbow flexion exercise performed to fatigue. The lactate accumulated in that study was between 3.6 and 3.8 mmoles/liter [10]. Our results conflict with Leal Junior and associates [5,8] who reported greater amounts of lactate accumulated with significant differences between phototherapy and placebo after fatiguing elbow flexion exercise. The minimal amount of lactate accumulated in this study was probably due to the small musculature involved in creating the handgrip motion when compared to the bicep brachii involved in elbow flexion. The effect of phototherapy on decreasing the amount of lactate accumulated following fatiguing exercise remains controversial.

The amount of DOMS created by the fatiguing handgrip exercise was negligible. The majority of the subjects reported zero pain on the 0-100 mm VAS scale. Possible explanations are that although the grip motion may involve a minimal eccentric contraction while releasing the grip, the movement was primarily isometric because the subjects were told to hold the contraction for three seconds. Although eccentric exercise is known as the primary facilitator of DOMS, unaccustomed physical exercise has also been cited as a factor [3]. Grip is a common activity that is utilized is daily. The grip exercise appears not to be a suitable exercise to utilize when studying the effects of DOMS.

There were no significant differences between the phototherapy

Condition	Red/Infrared	Blue/Infrared	Placebo
Number of Repetitions	15.71 ± 8.54	13.57 ± 6.64	13.93 ± 6.87
LA (mmoles/liter)	2.58 ± 0.86	2.36 ± 0.93	2.56 ± 0.57
VAS 24-Hour (0-100 mm)	2.86 ± 6.83	1.43 ± 5.35	0.01 ± 0.37
VAS 48-Hour (0-100 mm)	1.50 ± 3.28	1.07 ± 2.90	0.00 ± 0.00

*Values are given as mean ± *SD*

Table 4: Number of Repetitions, Lactate Accumulated (LA) and VAS Scores.

and placebo conditions on improving grip endurance in healthy young active adults. The results of our investigation are in agreement with the works of Gorgey et al. [23] and Leal Junior et al. [7,9]. Gorgey et al. [23] reported that the application of phototherapy did not attenuate the muscle fatigue evoked by neuromuscular electrical stimulation. Leal Junior et al. [7,9] investigated the effects of phototherapy on improving performance of the Wingate test, an anaerobic test utilizing a lower body ergometer. The Wingate is an all-out thirty-second test that measures anaerobic capacity of the lower extremities. They concluded that they did not show any improvement because they only applied the phototherapy to the knee extensors and the Wingate motion is a result of multiple muscles and joints. However, De Marchi et al. [11] demonstrated a significant improvement in running performance by applying phototherapy to the knee extensors, flexors and plantarflexors versus a placebo. The subjects improved their VO_{2max} by 1.1 ml/kg•min. Their results were statistically significant but were they clinically significant? Our results conflict with the finding of Baroni et al. [4] and Leal Junior et al. [5,6,8,10] who demonstrated that phototherapy utilizing various types of equipment and parameters improved elbow flexion endurance in young healthy adults, The subjects in the Leal Junior et al. [5,6,8,10] studies were professional athletes. The use of professional athletes may have limited the external validity of their results because of the physical characteristics and abilities of those subjects in comparison to average healthy young adults.

The two variables that appear to play an important role in the success of phototherapy in improving endurance are the irradiation of the entire muscle involved and proper dosage. Dosage can be reported as joules (J), which is a measure of radiant energy, or joules per cm2, which is a measure of fluence or energy density. The success of previous studies on improving muscle endurance were due to the application of phototherapy with greater radiant energy reflected by greater amount of total joules delivered to more points within the muscle and by greater energy densities applied. Muscle endurance was improved when the total joules delivered was between 20 and 260 [4-6,8,10-12]. Studies that utilized 7 and 12 J were not successful [7,23]. Our study utilized between 35.1 and 40 J per point but we only applied it to one point on each of the three muscles that we irradiated. We utilized dosage that was comparable to the successful studies; however we only irradiated one point per muscle. Enwemeka reports that dosage should be reported as energy density in J/cm^2. The majority of successful studies [4-6,10-12] utilized reported energy density dosages between 165 and 1,785 J/cm^2. According to Huang et al. [25] dosages as high as 50 to 100 J/cm^2 lose their beneficial effect and may even become detrimental due to the Arndt-Schultz curve. They state that dosage required for tissue healing, reducing inflammation and pain is between 3 and 5 J/cm^2 [25]. The World Association of Laser Therapy recommended treatment doses are expressed in joules and are between 4 to 6 J per point [26]. Enwemeka [24] states that the field is still in its infancy and we still do not have specific guidelines concerning dosage in order to achieve specific outcomes for a variety of clinical scenarios. The main limitation for our study appears to the total dosage applied and the sites utilized were not comparable to the successful studies [4-6,8,10-12]. However, are those high dosages clinically safe?

Conclusion

In conclusion, the application of a standard therapeutic dosage of phototherapy did not improve grip endurance. There appears to be a discrepancy in the dosage required for tissue healing, reducing inflammation and pain which appears to be much lower than the dosage required for improvement in athletic and muscle performance. Is the dosage required for improvement in muscle performance safe? The question remains to the feasibility of utilizing phototherapy for performance enhancement. What is the practicability and safety of applying phototherapy to all the muscles involved in a specific athletic activity? The role of phototherapy on improving athletic performance remains controversial.

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