Apparel with Far Infrared Radiation for Decreasing an Athlete's Oxygen Consumption during Submaximal Exercise

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ABSTRACT

Far infrared radiation (FIR) has been shown to have physiological effects when used as a treatment modality for certain medical conditions. Athletic apparel are currently commercially available that are constructed with fabrics that purportedly emit FIR. If apparel with this technology are capable of inducing positive physiological effects, then there may be important implications when worn by an athlete during exercise. The purpose of this study is to examine whether FIR apparel has an effect on oxygen consumption during exercise at submaximal intensities. Twelve male cyclists have completed submaximal incremental cycling tests. Each subject is tested on 4 separate days, twice while wearing a full body Control garment, and twice while wearing a similar garment made out of FIR fabric. Throughout each cycling test, the volume of oxygen uptake is monitored by using a breathing mask and metabolic analysis cart. At lower cycling intensities, the subjects consume statistically significantly less oxygen when wearing the FIR apparel compared to the Control garment, despite performing the same amount of mechanical work. Additional research is required to determine the implication of this effect for a training or competing athlete; however, the results indicate that this apparel technology does elicit a physiological effect.

***Keywords*:** Athletic Apparel, Far Infrared Radiation, Oxygen Consumption, Performance

1. Introduction

Far infrared radiation (FIR) is a subdivision of the electromagnetic radiation spectrum that has been investigated for biological effects (Vatansever & Hamblin, 2012). The FIR band comprises the longest wavelengths (λ = 3 - 100 µm) of the infrared radiation band. FIR transfers energy purely in the form of heat, which can be perceived by the thermoregulators in human skin as radiant heat (Plaghki et al., 2010).

Laboratory studies have shown that FIR emitting heat lamps can induce positive effects. Yu et al. (2006) found that FIR increases skin blood flow in rats. Toyokawa et al. (2003) reported that FIR significantly quickens skin wound healing in rats. Akasaki et al. (2006) showed that FIR could induce angiogenesis in mice with hindlimb ischemia. The findings of Ishibashi et al. (2008) suggest that FIR may suppress the proliferation of some human cancer cell lines.

FIR is not limited to powered devices: ceramic materials can emit FIR depending on their temperature (Liang et al. 2008; Wang et al. 2010). The nanoparticles of such ceramic materials can be incorporated into fibers and then woven into fabrics and manufactured into wearable apparel; theoretically, body heat would cause the ceramics to emit FIR. Such apparel have been linked to positive physiological effects; FIR gloves were reported to help treat arthritis of the hands and Raynaud's syndrome (Ko & Berbrayer, 2002), FIR belts were found to reduce body measurements (Conrado & Munin, 2011) and menstrual pain (Lee et al., 2011), and FIR socks were shown to have a beneficial impact on chronic foot pain (York & Gordon, 2009).

If FIR apparel is capable of inducing positive physiological effects, then there may be important implications if applied to sport. As an athlete could wear FIR apparel at any time, this type of apparel could possibly help an athlete warm up before exercise, enhance performance during competition, and/or facilitate recovery post exercise. The purpose of this study is to examine

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whether FIR apparel has an effect on oxygen consumption during submaximal exercise.

2. Methods

Twelve male aerobically fit recreational cyclists are recruited for this study. The height, mass, body mass index (BMI), and age of each subject are shown in Table 1. Informed written consent was obtained from all subjects prior to data collection in accordance with the Conjoint Health Research Ethics Board at the University of Calgary.

Table 1. Characteristics of the test subjects.

Subject	Height [m]	Mass [kg]	BMI [kg/m^2]	Age [yrs]
1	1.85	92.9	27.1	29
2	1.75	73.8	24.1	24
3	1.88	76.2	21.6	21
4	1.73	69.5	23.2	26
5	1.82	83.8	25.3	28
6	1.74	78.2	25.8	30
7	1.76	72.0	23.2	32
8	1.75	69.1	22.6	34
9	1.75	75.8	24.8	23
10	1.86	80.3	23.2	23
11	1.84	87.9	26.0	22
12	1.81	83.8	25.6	22

Two full body, non-compression apparel conditions were tested; one with FIR properties (termed FIR) and one without (termed Control). The fabrics for both apparel conditions were obtained from Hologenix LLC. The Control apparel was built by using 180 grams/m^2 fabric woven from polyethylene terephthalate (PET) and spandex fibers. The FIR apparel was built by using 180 grams/m^2 fabric woven 70% with PET fibers embedded with 1.25% by weight FIR that emitted ceramic nanoparticles (silicon dioxide, alumina oxide, and titanium dioxide), and 30% with standard PET and spandex fibers. The apparel consisted of pants with an elastic waistband and a long sleeved shirt (Figure 1). Both conditions were visually identical, except for a code written on a label on the inside of the clothing. Four sets of the apparel were built in a range of sizes (small, medium, large, and extra-large) in order to ensure that each subject had an appropriate fit. The apparel were machine washed after each use by using a warm water cycle and mild commercially available laundry detergent.

In general, the data collection sessions comprised a subject who cycled on a cycle ergometer at a constant cadence while the workload was increased every two minutes. During this exercise test, oxygen consumption data were continuously collected by using a TrueMax 2400 metabolic cart (ParvoMedics, Salt Lake City, USA), and blood samples were drawn from a fingertip every two minutes to measure blood lactate concentration with a Lactate Pro analyzer (Arkray Inc., Kyoto, Japan). Each subject completed four test sessions (two per apparel test condition), with each session being at least 48 hours apart. The subjects were instructed to refrain from any behavior outside of their normal physical activity, diet, and sleeping patterns during their entire testing period.

Fig. 1. Photograph of the test apparel.

Immediately prior to each data collection session, the metabolic cart, lactate probe, and cycle ergometer resistance were calibrated. As soon as the subject arrived, height and mass were measured and the subject was given the test apparel and asked to go change (the apparel test order was randomized for each subject). The exercise physiologist who was running the data collection sessions determined the starting cycle ergometer workload (100, 125, or 150 W) of each subject, depending on the size and fitness level of the athlete: this was determined during the first session of each subject and applied to all sessions.

The subjects warmed up for the test by cycling for 5 minutes at a workload 25 W below their defined starting workload at a self-selected ‘easy’ and ‘natural’ cadence. After the warm up, a resting blood lactate measurement was taken to ensure that the value was less than 2 mmol/L. At this time, a breathing mask (including head gear and nose clip) was put on the subject, and connected to the metabolic cart.

To begin the test, the subject started pedaling at their starting workload at a maintainable cadence between 80-90 rpm (the ergometer displayed cadence in real time for feedback to the subject and exercise physiologist for monitoring purposes); whatever cadence the subject naturally adopted at the very beginning of their first session was set as their cadence for the rest of the test and all following test sessions. At the two minute mark, the first blood lactate sample was taken, and the cycle ergometer workload was increased by 25 W. Every two minutes, blood was again sampled and workload increased another 25 W. During the first collection session of each subject, as soon as the blood lactate reading was greater than 6 mmol/L, the workload that the subject was currently cycling at was defined as their final workload, after which the test session was ended.

The first test session therefore established the initial and final workloads (and so also trial duration) that the subject would begin and end at in all four test sessions (Table 2). As such, each subject performed the same amount of mechanical work in each of their four test sessions; increasing in relative intensity from a blood lactate concentration less than 2 mmol/L to greater than 6 mmol/L.

Table 2. Test protocol details for each subject.

Subject #	Initial Workload [W]	Final Workload [W]	Trial Duration [min]
1	125	300	16
2	125	300	16
3	150	325	16
4	125	300	16
5	125	375	22
6	100	250	14
7	125	275	14
8	125	350	20
9	100	250	14
10	125	350	20
11	100	275	16
12	100	325	20

For each test session, the blood lactate data were plotted against time, and a curve was best fit to the data. The equation for this best fit curve was used to calculate the time at which the blood lactate concentration of the subject reached 2, 4, and 6 mmol/L. These time points therefore define three relative intensity intervals: < 2 mmol/L, 2 - 4 mmol/L, and 4 - 6 mmol/L. The oxygen consumption data were integrated over these intervals to determine the volume of oxygen consumed by the subject when cycling within each relative intensity (the data in Figure 2 in the Results section illustrate this analysis procedure).

For each subject, the data from the two test sessions were averaged for each apparel condition. The data were checked for normality by using Shapiro-Wilk tests, and then paired t-tests or Wilcoxon signed-rank tests were used to identify statistically significant differences between apparel conditions at the $\alpha = 0.05$ level.

3. Results

The graph in Figure 2 shows the raw oxygen consumption and blood lactate concentration data for the first trial of Subject 1. The graph also illustrates how the blood data points are used to define a best fit curve, the function of which identifies the times when the subject reached blood lactate concentrations of 2, 4, and 6 mmol/L. These time markers establish the intervals over which the oxygen consumption data are integrated.

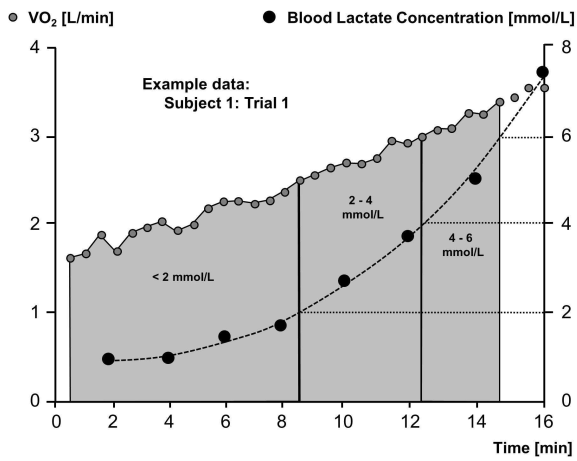

Fig. 2. Raw data from the first trial of Subject 1. Three relative intensity intervals are defined: <2, 2 - 4, and 4 - 6 mmol/L. Total oxygen consumed during each of these 3 intervals is calculated and compared between conditions.

On average, the subjects were in the < 2 mmol/L interval for 432 s, during which they consumed

15.40 L of oxygen with a day to day standard deviation of 0.32 L. The subjects were in the 2 - 4 mmol/L interval for 255 s, during which they consumed 11.81 L of oxygen with a day to day standard deviation of 0.25 L. The subjects were in the 4 - 6 mmol/L interval for 158 s, during which they consumed 8.92 L of oxygen with a day to day standard deviation of 0.20 L. There is no statistically significant difference in interval time between the two apparel conditions for any of the three intensity levels.

The mean oxygen consumption values for each apparel condition are shown for each interval in Table 3. In the < 2 mmol/L interval, the subjects consume statistically significantly less oxygen in the FIR condition than the Control condition; 1.1% less oxygen on average. In the 2 - 4 mmol/L interval, the subjects consume statistically significantly less oxygen in the FIR condition than the Control condition; 0.9% less oxygen on average. There is no statistically significant difference between conditions in the 4 - 6 mmol/L interval.

Table 3. Oxygen consumption results for each intensity level. The mean values are the average of all 12 subjects.

< 2 mmol/L	Control	FIR
Mean O_2 Consumed	15.48 L	15.31 L
p-value	0.014	
% Difference	1.1%	
2 - 4 mmol/L	Control	FIR
Mean O_2 Consumed	11.87 L	11.76 L
p-value	0.048	
% Difference	0.9%	
4 - 6 mmol/L	Control	FIR
Mean O_2 Consumed	8.94 L	8.90 L
p-value	0.511	
% Difference	---	

The individual responses of the subjects to the FIR apparel are not statistically significantly correlated with their mass, height, or BMI.

4. Discussion

The purpose of this study is to examine whether athletic apparel that emit FIR has a measurable physiological effect on athletes during submaximal exercise. Prior research has shown that apparel that emit FIR can have an effect on certain medical conditions (Vatansever & Hamblin, 2012), but it has not been shown if the effects of this apparel technology extend to an exercising athlete.

The results of this study show that apparel that emit FIR can have an effect on an athlete during exercise. When the subjects were cycling at lower intensities (blood lactate concentrations of < 2 mmol/L and 2 - 4 mmol/L) they consumed statistically significantly less oxygen when wearing the FIR apparel compared to when they were wearing the Control apparel (Table 3). On average, this difference in oxygen consumption is 1.1% for the < 2 mmol/L interval, and 0.9% for the 2 - 4 mmol/L interval. There was no difference in oxygen consumption for the 4 - 6 mmol/L interval; it appears that the benefit provided by the FIR apparel is greatest at lower exercise intensities and diminishes as intensity increases.

These results show that the FIR emitting apparel does have an effect on oxygen consumption. However, it is unknown if the oxygen consumption benefit occurs at a high enough intensity to provide a cyclist with a competitive advantage during an endurance race. Theoretically, the race pace of an endurance cyclist would be slightly below their anaerobic threshold, near a blood lactate concentration of 4 mmol/L (Heck et al., 1985; Kindermann et al., 1979; Sjodin & Jacobs, 1981; Skinner & McLellan, 1980). In this study, the subjects consume less oxygen in the FIR apparel when cycling at intensities less than 4 mmol/L, but there is no effect when cycling above 4 mmol/L. Therefore, it is unclear from these results whether the FIR apparel would provide a benefit when cycling at an endurance race pace. A future experiment that examines oxygen consumption while subjects cycle at their endurance race pace would be required to determine if there is a benefit to wearing the FIR apparel.

The mechanism by which the FIR apparel decreases oxygen consumption is unknown and is not elucidated in this experiment. It has been hypothesized that FIR may stimulate the release of nitric oxide and cause vasodilation (Vatansever & Hamblin, 2012), which could increase blood circulation and the ability of the body to deliver oxygen to the working muscles. However, verification of whether this is in fact what occurred is beyond the scope of the present experiment. To the knowledge of the authors, there are no studies to date that have conclusively demonstrated the mechanism by which FIR elicits positive physiological effects.

5. Conclusion

Apparel that emit FIR have been previously shown to elicit physiological effects in humans (Conrado & Munin, 2011; Ko & Berbrayer, 2002; Lee et al. 2011; York & Gordon, 2009). The results of this study show that this apparel technology can also have a physiological effect on athletes during exercise. When cycling at lower relative intensities (< 4 mmol/L), the subjects consume approximately 1.0% less oxygen when wearing FIR emitting apparel. This effect diminishes with increasing cycling intensity; therefore, further study is required to determine if this effect is relevant for a competing endurance cyclist.

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