Apparel that Emit Far Infrared Radiation can Decrease 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 was to examine whether FIR apparel had an effect on oxygen consumption during exercise at submaximal intensities. Twelve male cyclists completed submaximal incremental cycling tests. Each subject was 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 was monitored using a breathing mask and metabolic analysis cart. At lower cycling intensities, the subjects consumed 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 increased skin blood flow in rats. Toyokawa et al. (2003) reported that FIR significantly quickened 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 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). Nanoparticles of such ceramic materials can be incorporated into fibers 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 reduce 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 was to examine whether FIR apparel had an effect on oxygen consumption during submaximal exercise.

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2. Methods

Twelve male aerobically fit recreational cyclists were recruited for this study. The height, mass, 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 University of Calgary's Conjoint Health Research Ethics Board.

Table 1. Characteristics of the test subjects.

Subject #	Height [m]	Mass [kg]	Age [yrs]
1	1.85	92.9	29
2	1.75	73.8	24
3	1.88	76.2	21
4	1.73	69.5	26
5	1.82	83.8	28
6	1.74	78.2	30
7	1.76	72.0	32
8	1.75	69.1	34
9	1.75	75.8	23
10	1.86	80.3	23
11	1.84	87.9	22
12	1.81	83.8	22

Two full body, zero 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 using fabric woven from polyethylene terephthalate (PET) fibers. The FIR apparel was built using fabric woven from PET fibers embedded with FIR emitting ceramic nanoparticles. 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, extra-large) in order to ensure each subject had an appropriate fit. The apparel were machine washed after each use using a warm water cycle and mild commercially available laundry detergent.

In general, the data collection sessions were comprised of a subject cycling on a cycle ergometer at a constant cadence while the workload was increased every two minutes. During this exercise test, oxygen consumption data were collected continuously using a ParvoMedics 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.

Figure 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 running the data collection sessions determined each subject's starting cycle ergometer workload (100, 125, or 150 W) depending on the size and fitness level of the athlete: this was determined during each subject's first session 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 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 for the subject and for the Exercise Physiologist to monitor); 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 for 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 each subject's first collection session, 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 workload and final workload (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 subject's blood lactate concentration reached 2, 4, and 6 mmol/L. These time points therefore defined 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 illustrates 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 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 Subject 1's first trial. The graph also illustrates how the blood data points were used to define a best fit curve, the function of which identified the times when the Subject reached blood lactate concentrations of 2, 4, and 6 mmol/L. These time markers established the intervals over which the oxygen consumption data were integrated.

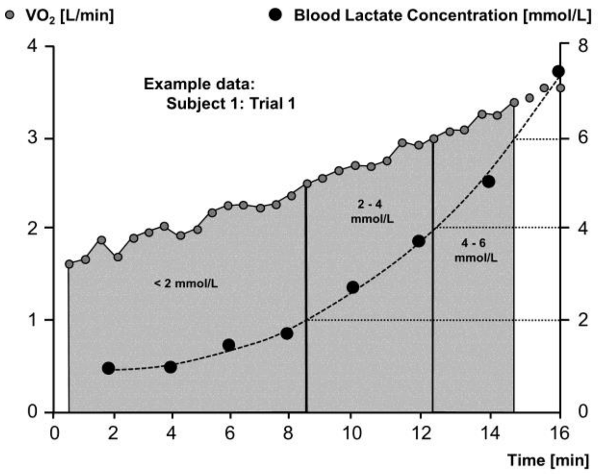

Figure 2. Raw data from Subject 1's first trial. Three relative intensity intervals were defined: < 2, 2 - 4, and 4 - 6 mmol/L. Total oxygen consumed during each of these 3 intervals was calculated and compared between conditions.

On average, the subjects were in the < 2 mmol/L interval for 432 s (SD: 196 s), the 2 - 4 mmol/L interval for 255 s (SD: 57 s), and the 4 - 6 mmol/L interval for 158 s (SD: 24 s). There was no statistically significant difference in interval time between the two apparel conditions for any of the three intensity levels.

Mean oxygen consumption values for all 12 subjects are shown for each interval in Table 3. In the < 2 mmol/L interval, the subjects consumed 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 consumed statistically significantly less oxygen in the FIR condition than the Control condition; 0.9% less oxygen on average. There was 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	---	

4. Discussion

The purpose of this study was to examine whether athletic apparel that emit far infrared radiation had 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 far infrared radiation 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 wearing the Control apparel (Table 3). On average, this difference in oxygen consumption was 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 did 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 had less oxygen consumption in the FIR apparel when cycling at intensities less than 4 mmol/L, but there was no effect when they were 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 examining oxygen consumption while subjects cycle at their endurance race pace would be required to determine this.

The mechanism by which the FIR apparel decreased oxygen consumption is unknown and was 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 so the body's ability to deliver oxygen to the working muscles. However, verifying whether this is in fact what occurred was beyond the scope of the present experiment.

To the authors' knowledge, there are no studies to date that have conclusively demonstrated the mechanism by which far infrared radiation elicits positive physiological effects.

5. Conclusion

Apparel that emit far infrared radiation have previously been 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 consumed approximately 1.0% less oxygen when wearing FIR emitting apparel. This effect diminished with increasing cycling intensity; therefore, further study is required to determine if this effect is relevant for a competing endurance cyclist.

Acknowledgements

Support for this study was provided by Hologenix LLC. This funding source had no role in study design, data collection, or interpretation of the results.

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