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Evaluating the Effect of Far Infrared-Embedded Fabrics on Muscle Activation and Blood Oxygen Saturation During Exercise

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ABSTRACT

This study examines the effect of Far Infrared (FIR) active fabrics on muscle activity and blood oxygen saturation during exercise. FIR fabrics, containing nano-ceramic particles, emit infrared radiation that promotes blood circulation and thermal regulation. A comparative experimental approach was used with 30 male participants performing standardized workouts while wearing three types of sportswear: fully FIR-integrated, traditional polyester-spandex, and a hybrid design combining both materials. Results showed that the FIR-based garments led to the highest oxygen saturation and the lowest muscle activation, indicating improved efficiency and reduced fatigue. Traditional sportswear required greater muscular effort and resulted in lower oxygen levels, while the hybrid model delivered moderate results. The findings underscore the physiological advantages of FIR textiles in enhancing performance and comfort. This research offers practical implications for the design of smart sportswear and supports the integration of nanotechnology-based fabrics to meet the needs of athletes and individuals engaged in physical training.

***Keywords**:* Smart Fabrics, FIR (Far Infrared Radiation) Fabric, Physiological Comfort, Muscular Performance, Nanotechnology.

Research Terminology:

1- Smart Fabrics:

Fabrics that intelligently respond to environmental changes such as temperature, humidity, and light, offering advanced functional benefits. In sportswear, these textiles are used to enhance physical performance and comfort, as well as support recovery through technologies like Far Infrared Radiation (FIR).

2- FIR (Far Infrared Radiation) Fabric:

Active fibers that emit far infrared radiation, used to enhance microcirculation, reduce muscle fatigue, and improve thermal comfort.

3- Physiological Comfort:

A state of thermal balance and physical ease by suitable clothing during physical activity.

4- Muscular Performance:

The ability of muscles to perform physical work efficiently, often measured by strength or endurance during exercise.

5- Nanotechnology:

The use of materials and techniques at the nanometer scale to improve fabric properties such as antibacterial resistance or moisture control.

1-Introduction

Sportswear is considered one of the most prominent types of functional clothing, as it contributes to enhancing athletic performance while ensuring high levels of comfort and ease of movement. The rapid growth of the sportswear market has driven manufacturers and designers to develop new fabrics and technologies, relying on microfibers and modern innovations, which have led to the production of more efficient garments tailored to the physiological needs of users. The design of modern sportswear is based on a deep understanding of the body's needs during physical activity, including ventilation, sweat absorption, temperature regulation, and flexibility. The study aims to investigate how functional properties of modern sports fabrics contribute to athletic performance and physiological comfort and evaluate their effectiveness in improving athletes' comfort and performance, thus supporting the selection of the most efficient materials for optimal athletic outcomes.

1-1- Research Problem:

With the continuous expansion in the use of smart fabrics and modern technologies in sportswear design, FIR (Far Infrared Radiation) fabric has emerged as one of the innovative materials believed to have a positive effect on physical performance and physiological comfort. Despite the progress in this field, there remains a research gap regarding the actual effectiveness of this fabric compared to traditional materials, particularly in terms of its impact on key indicators such as body temperature, sweat rate, muscular performance, and overall comfort during exercise. From this standpoint, the research problem can be formulated as follows: **"To what extent does the use of FIR fabric in sportswear affect muscular performance and blood oxygen saturation compared to traditional fabrics?"**

1-2- Research Objectives:

1. To identify the properties and working mechanism of FIR fabric.
2. To design a prototype of sportswear incorporating FIR fabric.
3. To examine the impact of FIR fabric on:
    - Muscular performance.
    - Blood oxygen saturation levels.
4. To compare the functional performance of sportswear made with FIR fabric versus traditional sportswear.

1-3- Research Methodology:

This study adopts an **experimental approach** to examine the effect of using FIR fabric in sportswear.

- **Study Sample:**
  The sample consists of **30 male participants** who regularly engage in physical activity.
- **Clothing Design:**
  A standardized outfit made with FIR fabric was designed for the **experimental group**, while the **control group** wore garments made from traditional fabrics.
- **Measurement Tools:**
  Measurements included **blood oxygen saturation levels** and **muscular activity**.

- **Research Procedures:**
  Participants were placed in a controlled environment to perform a specified exercise, during which relevant data was recorded and analyzed.

- **Statistical Analysis Tools:**
  Means, standard deviation, and the **T-test** were used to analyze the data.

2- Literature Review:

2-1 Feryal Saeed Ahmed Salloum (2018)

Title: "A Study of the Functional Performance Properties of Some Modern Sportswear Fabrics"
This study compared the functional performance properties of four types of fabrics used in modern sportswear by conducting several tests, including:
- Fabric weight per square meter- Thickness- Air permeability- Water vapor permeability- Thermal insulation- Wetting properties- UV permeability resistance- Bursting strength- Static electricity- Pilling resistance- microscopic surface analysis.

Table (1). shows the comparative fabrics.

No.	Fabric Type	Blend Composition	Fabric Weight (g/m^2)	Thickness (cm)
1	CoolMax	50% CoolMax, 50% Polyester	149	0.018
2	Spandex	90% Nylon, 10% Spandex	264	0.022
3	ColdBlack	95% Polyester, 5% Elastane	217	0.026
4	Local Polyester	100% Polyester	166	0.023

Key Findings:
- Cool-Max fabric showed the best performance in air permeability, water vapor permeability, and thermal insulation, followed by local polyester, then Cold-Black, and finally Spandex.
- All fabric samples showed excellent UV resistance, with Spandex achieving the highest level of protection.
- Cool-Max and Spandex recorded the lowest values in static electricity, followed by polyester, while Cold-Black had the highest.
- Polyester had the highest bursting strength, followed by Spandex, then Cool-Max, and lastly Cold-Black.

- In terms of wetting speed, Cool-Max performed best, followed by Cold-Black, polyester, and finally Spandex.
- All fabric samples exhibited high resistance to pilling.

2-2 Devanand Uttam (2013)

This study emphasized the key characteristics that sportswear fabrics should possess:

- Thermal Insulation: to help maintain body temperature under various conditions.
- Moisture Absorption: to absorb and transport sweat away from the body to keep it dry.
- Antibacterial Properties: to reduce microbial load and maintain personal hygiene.
- UV Resistance: to protect the skin from harmful ultraviolet rays, especially during outdoor activities.

3- Functional Clothing:

Functional clothing has become an essential and necessary element in the ready-to-wear apparel industry. Its role is no longer limited to protection against weather conditions or providing warmth, but has expanded to meet more specialized needs, such as absorbing sweat and wicking it away from the body. This contributes to enhancing the feeling of comfort, which in turn positively impacts human performance.

The core function of such clothing depends on how well it aligns with the body's needs, which requires selecting suitable materials based on their intended use. Functional clothing applications vary across many sectors, including hospital staff, firefighters who face respiratory challenges, and sportswear specifically designed to improve performance and ensure comfort during exercise.

The importance of this type of clothing lies in providing the highest levels of comfort for the wearer, in addition to addressing common issues such as moisture control and temperature regulation. Functional garments also include specialized designs such as UV-resistant clothing, antibacterial fabrics, and odor-resistant materials, reflecting the advancement of textile technologies to meet the growing demands of consumers (Abdel-Hamid, W. T. M.,2020).

- **Classification of Functional Clothing:**

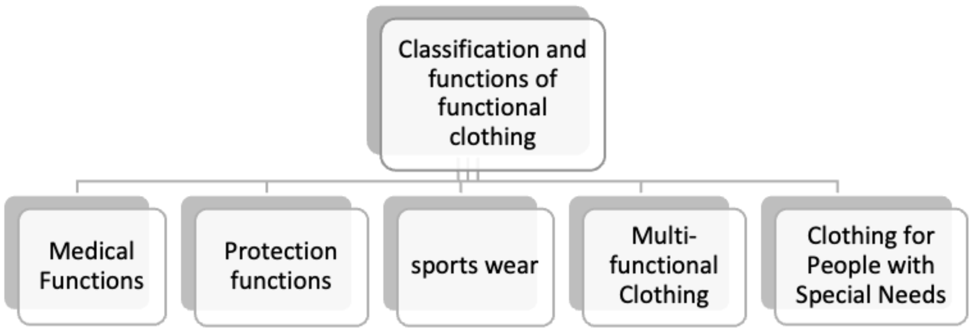

Fig (1). illustrates the classification of functional clothing
(Abdel-Hamid, W. T. M.,2020)

3-1 Sportswear:

Sportswear is considered one of the most diverse and rapidly growing categories of functional clothing, as it plays a vital role in enhancing athletic performance while providing the highest levels of comfort. It helps athletes reach their full potential by employing the latest textile manufacturing technologies and innovations in design that support the athlete, offering physiological comfort during training and freedom of movement without adding extra burden.

In recent years, there has been a significant increase in sportswear sales, prompting textile developers, manufacturers, and sportswear designers to place greater emphasis on improving the properties of these garments and fostering innovation. Recently, technologically advanced fibers have been introduced, characterized by their high efficiency and ability to provide elevated levels of comfort and luxury. Modern sportswear design also takes into account the physiological aspects of body movement, as comfort and functionality are indispensable elements for improving athletic performance.

3-1-1 Types of fabrics used in sportswear include:

- **Natural Cotton Fabrics:**

To this day, most people continue to rely on cotton undergarments—such as cotton vests and shorts—due to their comfort and ability to prevent skin irritation. However, cotton is considered an unsuitable choice for sports activities, particularly in high-humidity environments, as it absorbs large amounts of sweat and retains it. This results in increased fabric weight, an intense feeling of cold, and the fabric sticking to the skin, causing discomfort during movement. According to sports medicine, the body's response to cold involves vasoconstriction, which slows down blood circulation and weakens the supply of oxygen and nutrients to organs and muscles. This, in turn, negatively affects muscular and physical performance. Additionally, a drop in body temperature may impair kidney function, weaken the immune system, and increase susceptibility to colds and infections. As a result of these issues, sportswear manufacturers have, in recent years, turned to the development of modern fabrics that are water-resistant and capable of regulating body temperature. These advanced materials help maintain a proper thermal balance during physical activity.

- **Synthetic Fabrics:**

  Manufacturers have increasingly turned to the use of various types of synthetic fabrics, particularly polypropylene and polyester fibers, due to their distinctive properties. Polyester is known for its high dimensional stability, excellent resistance to dirt, alkalis, and mildew, as well as its ability to withstand high temperatures. It also has good moisture-wicking capabilities and a low absorption rate, making it easy to care for and cost-effective—qualities that make it an ideal choice for sportswear production.With recent advancements in textile manufacturing technologies, synthetic fabric compositions have undergone enhancements that have made them more appealing to consumers. Sportswear made from these materials has become lightweight, quick-drying, and well-insulated, with a soft texture that closely resembles natural cotton fabrics. These garments also possess excellent moisture management properties, which help regulate body temperature, improve muscle performance, and delay the onset of fatigue—factors that have contributed to their widespread popularity among athletes and fitness enthusiasts.

The most important types include:

1- Thermo Max Fibers:

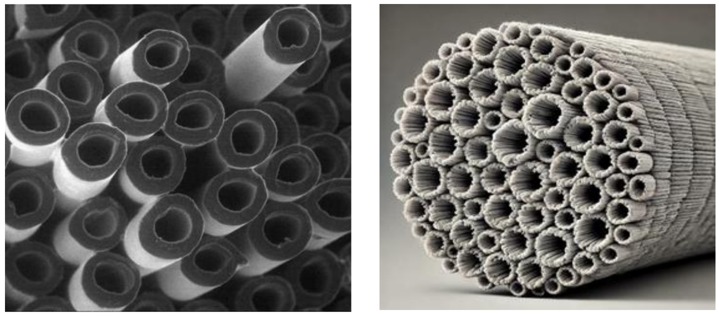

Fig (2). illustrates thermal fibers

Among the advanced synthetic fibers, hollow fibers stand out as a significant innovation. These fibers are characterized by an internal cavity that imparts unique properties. The concept of hollow fibers was inspired by nature—specifically the fur of polar bears, which contains hollow hair strands that trap still air, providing effective thermal insulation for warmth. Based on this natural phenomenon, scientists developed synthetic fibers with a central cavity that retains still air, granting them high thermal insulation capacity and enhanced warming properties. Additionally, these fibers possess a permeable surface that allows for efficient absorption of sweat from the body and its rapid evaporation into the surrounding air. This contributes to increased comfort during wear.

2- Cool Max Fibers:

Fig (3). illustrates Cool Max fibers

These fibers are considered a type of advanced synthetic fiber, with each filament containing multiple internal cavities. The air within these cavities interacts with the external air, creating continuous airflow within the filament, which contributes to generating a cooling sensation.

Thanks to these properties, such fibers are commonly used in the production of garments specifically designed for hot climates, as they help provide thermal comfort and reduce the

3- Microfiber:

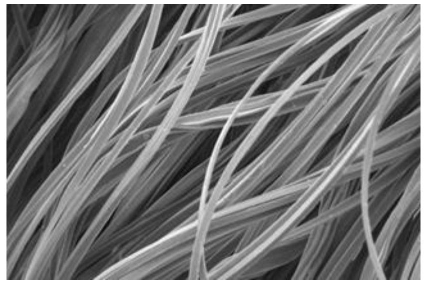

Fig (4). illustrates Microfibers (Abdel-Hamid, W. T. M.,2020).

Microfiber refers to ultra-fine synthetic filaments that are spun in a dissolved, rather than twisted, form—giving the resulting fabrics excellent coverage while maintaining the required breathability. Due to these characteristics, microfiber is used in the production of lightweight, water-repellent fabrics, as well as in applications such as water and air filters.

Microfibers are produced through a technique that involves creating bicomponent filaments made of two different polymers, which are spun into yarns and later woven into fabrics. During the finishing processes, the polymers separate, transforming each filament into extremely fine strands known as microfibers—with a fineness reaching as low as 0.05 denier, giving them exceptional softness.

Generally, microfiber refers to synthetic fibers with a diameter of less than 1 denier or below 1 decitex (dtex). These fibers are finer and softer than most natural and synthetic fibers, resulting in fabrics with an exceptionally smooth and flexible texture.

When comparing microfiber to natural fibers, natural silk is considered the finest, ranging between 1–1.3 denier, followed by cotton (1.4–2 denier), and wool (3–5 denier), which is among the thickest natural fibers. As for synthetic fibers, they typically range from 1–3 denier, depending on their intended end-use—whether in cellulose-based or protein-based textiles.

Classification of microfiber filaments by fineness:

- Fine fibers: up to 1.3 dtex
- Extra fine fibers: less than 1.0 dtex
- Ultra-fine microfiber: less than 0.1 dtex (Abdel-Hamid, W. T. M.,2020).

3-1-2- Modern Fibers in Sportswear:

With technological advancements, new-generation fibers have emerged, offering numerous benefits that make them ideal for use in sportswear.

• Nanofibers:

Nanofibers are characterized by their extremely small diameter—less than 100 nanometers—which grants them unique properties such as light weight, durability, and enhanced interaction with environmental elements. In sportswear, nanofibers are used to create fabrics with superior moisture absorption capabilities, enabling quicker drying of the skin and improving comfort during intense physical activity.

• Bicomponent Fibers:

Bicomponent fibers have long been utilized in the development of technical textiles. These fibers consist of two polymers that differ either chemically, physically, or both. They can be made from two types of the same fiber—such as two variations of nylon or acrylic—or from entirely different fibers such as polyester and nylon, or nylon and elastane.
Based in Belgium, the company *Centexbel* operates a facility for the extraction of bicomponent fibers. Various types of bicomponent fibers are produced depending on their intended end use.*(Hayes S., 2016)*.

• Smart Fibers:

Smart fibers are fibers that can respond to environmental stimuli such as heat or moisture. These fibers are ideal for sportswear as they can alter their properties in response to surrounding conditions, such as changing the fiber's size in response to temperature, which helps improve thermal comfort and moisture balance in athletic garments.

• Microfibers:

Microfibers are synthetic fibers manufactured with an extremely fine linear density, ranging from 0.4 to 0.9 dtex, making them exceptionally lightweight. Fabrics made from microfibers exhibit extraordinary strength, durability, moisture permeability, and a soft touch. Microfiber-based fibers are commonly available in polyester, polyamide, acrylic, polypropylene, and cellulose. These fibers provide a highly porous structure, enhanced water absorption, and excellent thermal regulation properties due to the extremely fine linear density of the fibers.

3-1-3 Use of Nanotechnology in Sportswear:

Nanotechnology can be utilized in the manufacturing of multifunctional sportswear through the development of nanofiber-like structures, nanofibers, and nanofabrics. These modern technologies enable the design of clothing that provides effective protection against harsh weather conditions such as wind, rain, and snow, while offering air and vapor permeability without liquid permeability, thus enhancing athletic performance in various environments.

For instance, the Korean company *Hyosung* has developed silver nanonylon fibers used in sportswear, running shoes, and sports bags. Through the application of nanotechnology, significant advancements have been made in the manufacturing of slip-resistant shoe insoles. Nanotechnology is an effective tool for improving the functionality of sportswear and footwear, with widespread applications aimed at enhancing performance, increasing comfort, and protecting athletes from environmental factors, as discussed in the following points *(Faheem Ahmad et al., 2023)*.

• Protection from Bacteria and UV Radiation:

Sweat from the athlete's body creates favorable conditions for bacterial growth, which may lead to infections or unpleasant odors. Some researchers have applied zinc oxide nanoparticles to sportswear to achieve antibacterial properties. Antibacterial agents like *Silverclear*™ have been used in the manufacturing of antibacterial sportswear and footwear. To avoid risks associated with silver, the concentration of silver applied to the fabric must be carefully monitored. UV protection is another area in sportswear. The efficiency of UV-blocking materials can be enhanced by the uniform distribution of nanoparticles on the fabric surface.

• Protection from Heat and Cold:

Many sports, such as diving, cycling, ice skating, and skiing, require sportswear with insulating properties. These sports affect body heat loss due to external factors and physical activity during the sport. To develop smart thermoregulating clothing, the application of PCMs (Phase Change Materials) in textile manufacturing has grown.

PCMs are categorized as follows:

(a) Organic, non-paraffin materials such as alcohols, glycolic acid, and fatty acids.

(b) Organic, paraffin materials like alkyl hydrocarbons.

(c) Inorganic materials and aqueous inorganic salts.

To reduce the reactivity of PCMs with the external environment, they can be encapsulated in nano capsules. Nanocapsules transfer heat at higher rates compared to microcapsules. Materials such as polystyrene, urea formaldehyde, silicone, and polymethacrylates are some of the encapsulating materials. Nanocapsules containing PCM can be integrated into textile materials during the fiber spinning process or applied as coatings using binders like polyurethane. Other methods of incorporating PCM into fabrics include electrospinning and composite techniques.

• Self-Cleaning with Nanotechnology:

The manufacturing of sportswear with self-cleaning properties is a prominent application of nanotechnology in textiles. Photocatalytic nanoparticles such as ZnO and TiO2 have been reported to produce a self-cleaning textile surface. These photocatalytic agents can be embedded into sportswear. *Nano-sphere™* has been produced by *Schoeller Textile AG* for manufacturing self-cleaning fabrics for sports textiles. Self-cleaning properties can be achieved through superhydrophobic and super hydrophilic surfaces.

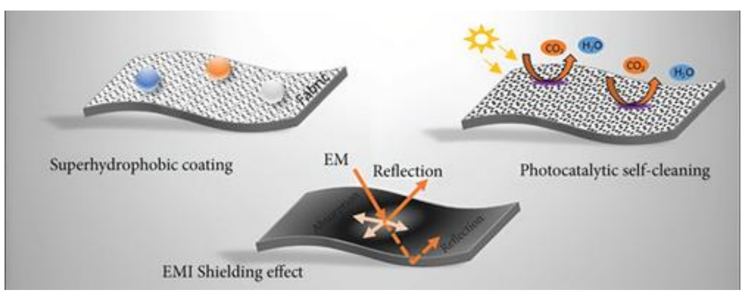

Fig (5). Illustrates the self-cleaning effect through coatings and photocatalytic stimulation, along with electromagnetic interference protection *(Faheem Ahmad et al., 2023)*.

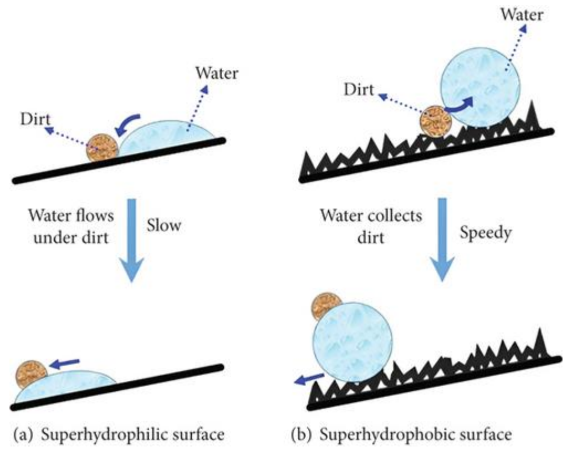

Fig (6). Shows a schematic representation of the self-cleaning process in superhydrophobic and super hydrophilic surfaces *(Faheem Ahmad et al., 2023)*.

• Multifunctional Properties Provided by Nanotechnology:

There is an increasing demand for sportswear that provides simultaneous protective functions against heat, cold, water, wind, odors, and bacteria. Such clothing is highly sought after for sports performed in extreme weather conditions, such as skiing, boating, and mountain climbing. To develop these types of garments, nanotechnology plays a crucial role. Self-cleaning, UV resistance, antibacterial properties, water-repellent and water-attracting behaviors, and photocatalytic properties can be integrated into textiles using metal oxide nanoparticles. It has also been reported that chemical corrosion resistance can be achieved through the application of carbon black nanoparticles. Additionally, carbon nanotubes have the potential to transmit thermal and electrical conductivity to textiles. Nanomaterial-based compounds have also been used in sportswear for rapid recovery from injuries during physical activities. *(Faheem Ahmad et al., 2023)*.

- In the context of utilizing **nanotechnology in sportswear**, its role is not limited to enhancing resistance to environmental factors or improving comfort; it also extends to **enhancing the thermal functionality of clothing**, as demonstrated by **Far Infrared (FIR) thermal textile** technology.

  One advanced application of this technology involves the integration of **nano-ceramic particles** into fabric fibers, as seen in the SPORTINGTEX® approach, which allows the fabric to absorb body heat or solar energy and convert it into **far infrared radiation** that reflects back to the body to enhance warmth and stimulate blood circulation.

Thus, incorporating these nano-particles not only adds thermal regulation capabilities, but also represents a significant extension of nanotechnology applications in smart, multifunctional sportswear—improving athletic performance across various environments by creating an **optimal thermal microclimate within the textile**.

4- Far Infrared (FIR) Thermal Textile:

Far Infrared (FIR) materials can be incorporated into textiles using various techniques such as **coating**, **lamination**, and **fiber spinning**. The FIR thermal textile technology developed by **SPORTINGTEX®** involves embedding **nano-ceramic particles** into polymer structures using a unique formulation that integrates the particles directly into the fabric fibers. When used in textile products—such as blankets or bed linens, particularly those in close contact with the human body—these ceramic particles can emit **far infrared radiation (FIR)**.

While increasing the amount of nano-ceramic powder in fabric fibers tends to enhance FIR emissivity, it is **technically recommended not to exceed a 5% concentration**. Excessive ceramic content can compromise the fiber's durability. At an optimal **5% concentration**, FIR emissivity (within a wavelength of 2–22 µm at 25°C) can reach **0.88 to 0.90**, according to certified testing laboratories. Therefore, it is essential that textile manufacturers **provide validated testing reports** to ensure quality and functional performance.

4-1- Mechanism of FIR Thermal Textile Functionality:

As the fibers are infused with ceramic powder, FIR textiles can **absorb solar energy** and re-radiate the **body's heat back to the skin**, enhancing thermal retention. Furthermore, when ceramic particles absorb energy, **their molecular activity increases**, resulting in **friction-induced heating** within the fiber structure.

These ceramic fibers **emit far infrared rays** in the **6–14 µm range**, closely matching the natural FIR wavelength of the human body. This similarity allows the radiation to be **readily absorbed by the body**, leading to a process called **resonance absorption**. This stimulates **water molecules** on the surface of deep skin cells, breaking them into **smaller molecular clusters**.

These smaller clusters generate heat through vibration and friction, which increases the **thermal interaction** within the fabric-skin interface.
Ultimately, the textile captures and circulates this thermal energy, creating an **effective warming effect** and enhancing **thermal comfort** for the wearer.

Practical Framework

The objective of this research is to examine the **functional performance of FIR fabric** and its **influence on athletic performance**. To fulfill this aim, a **comparative experimental study** was conducted between FIR fabric and a locally manufactured sports fabric. The study involved the **design and production of three sports T-shirts**, allowing for a practical assessment of the FIR fabric's effectiveness in enhancing physical performance, in contrast to traditional sportswear materials.

1. Technical Specifications of the Fabrics Used

To ensure accuracy and reliability in the comparison, **two fabrics with comparable structural properties** were selected. This controlled approach was adopted to precisely evaluate the performance of the FIR textile under investigation.

Table (2) Technical Specifications of the Fabrics Used

Specification	FIR Fabric	Local Fabric (Polyester)
Weight	252 grams	250 grams
Fabric Width	62 inches	60 inches
Composition	85% Polyester – 15% Spandex	90% Polyester – 10% Spandex

Laboratory Tests:

Eight laboratory tests were conducted on the fabric under study (Far Infrared - FIR textile) to evaluate its physical and functional properties. All tests were performed at the **National Research Centre**, except for the **Spectral Emissivity** test, which was carried out at the **Tze-Chiang Foundation of Science and Technology** in China.

The conducted tests included:

1. Air permeability test
2. Thermal conductivity test
3. Fabric thickness test
4. Liquid moisture management properties test
5. Pilling resistance test
6. Electrostatic properties test
7. Scanning and mapping
8. Far Infrared spectral emissivity test

Design Phase:

In this phase, initial designs of the sports T-shirts were developed to align with the study objectives, with a focus on balancing aesthetics and functionality.

Cuts and fits were carefully selected to ensure comfort and freedom of movement during physical activity, while also targeting muscle areas to enhance athletic performance.

The designs included:

- **Design A:** Fully made using the fabric under study (FIR fabric).
- **Design B:** Fully made using a local athletic fabric composed of polyester and spandex.
- **Design C:** A hybrid design combining the FIR fabric with the local polyester-based fabric.

Production Phase:

During this phase, custom patterns for the sports T-shirts were prepared according to the defined specifications, with a focus on measurement precision to ensure optimal fit.

The cutting and assembly processes were carried out at **Nuno Tex Sportswear Factory**, following approved quality standards to ensure the final product meets the required functional performance.

Tests Conducted in the Gym:

Athletic performance tests were conducted on the **three designs** using an **elliptical machine**, aiming to assess the impact of the fabric under study on **muscle activation** and **blood oxygen**

levels.

All constant variables were controlled to ensure consistent and reliable results. Each session lasted for **10 minutes**, starting with **5 minutes at a moderate speed**, followed by **5 minutes at a high speed**.

Participants with **good physical fitness and general health** were selected to ensure accurate results that reflect the fabric's effect on **enhancing muscular activity** and **improving the efficiency of oxygen distribution throughout the body** during exercise.

Test Results:

A test was conducted on the **first design made with FIR fabric**, involving **30 participants**. Each individual's comfort and physical performance were assessed before the workout, followed by continuous monitoring during a **10-minute exercise session**.

Data analysis focused on several key indicators, including **blood oxygen levels**, **and muscle activity**, in order to evaluate the **effectiveness of the design in enhancing physical performance** during exercise.

Table (3) presents the readings of **blood oxygen saturation**

Status (Trainee)	Oxygen percentage (%)			
	Average during exercise for design C	Average during exercise for design B	Average during exercise for design A	While resting
1	95	93	95	96
2	95	93	95	98
3	95	92	94	97
4	95	93	94	95
5	95	93	95	98
6	94	92	94	96
7	95	91	94	97
8	94	92	95	97
9	94	92	95	97

10	94	90	94	98
11	93	91	94	98
12	95	92	95	98
13	94	91	94	97
14	94	92	94	97
15	94	90	94	98
16	93	92	94	95
17	94	93	95	96
18	94	93	95	97
19	93	92	94	96
20	93	91	94	96
21	93	91	94	97
22	95	92	94	96
23	93	90	94	98
24	94	92	95	97
25	94	93	95	98
26	94	93	95	97
27	94	92	94	98
28	92	91	93	95
29	93	91	94	97
30	92	90	93	96
mean	93.9	91.8	94.3	96.9
Standard deviation	0.88	1.01	0.60	0.97

Table (4) presents the readings of **Muscle activity µv**

Status (Trainee)	Muscle activity µv			
	Average during exercise for design C	Average during exercise for design B	Average during exercise for design A	While resting
1	780	950	750	200
2	650	895	624	198
3	750	960	740	155
4	720	900	749	200
5	800	920	765	169
6	700	915	699	205
7	750	892	769	198
8	780	860	799	260
9	750	960	763	221
10	785	945	790	155
11	750	945	702	210
12	744	868	743	166
13	770	879	769	258
14	750	960	763	221
15	775	945	770	193
16	726	896	718	252
17	764	940	738	300
18	685	885	701	199
19	725	919	754	311
20	757	945	793	286
21	715	905	689	225
22	744	890	741	259
23	774	889	753	254

24	790	965	800	219
25	775	945	780	198
26	700	919	697	255
27	760	902	743	198
28	770	879	769	258
29	750	960	763	221
30	775	945	770	193
mean	748.8	919.3	746.8	221.2
Standard deviation	33.89	31.72	38.39	40.41

Using the data in Table (1) and Table (2), the effect of exercise on the player's performance was studied by wearing three different designs of sports T-shirts, which were as follows:

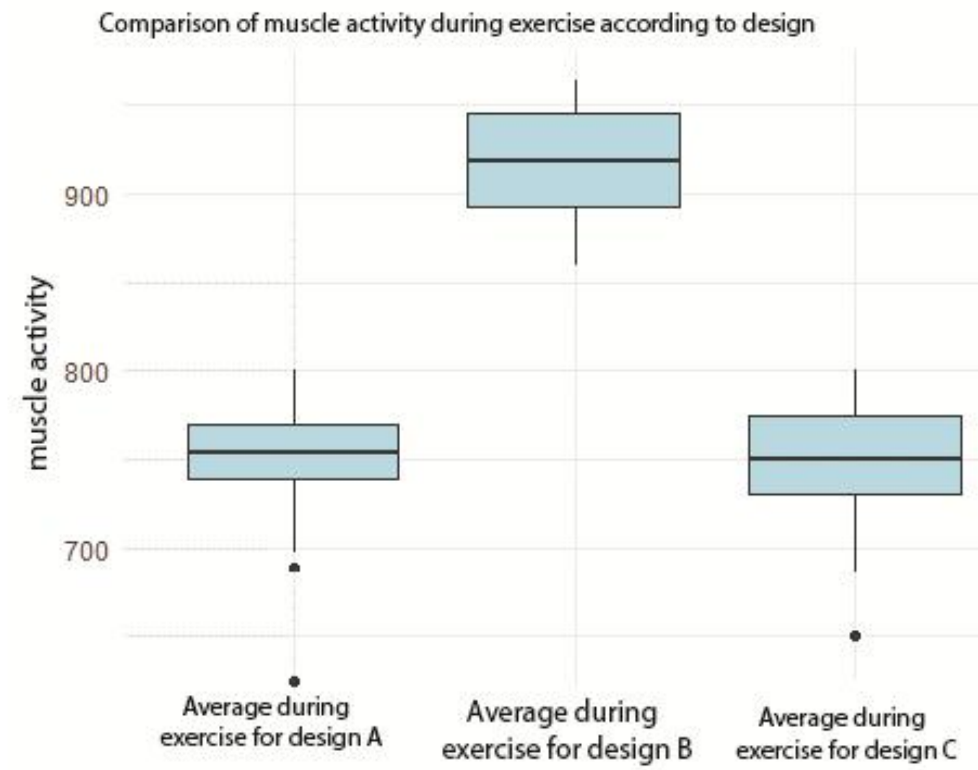

Fig (7). Comparison of muscle activity during exercise according to the different exercise designs according to the design

The graph (1) shows the distribution of muscle activity levels during exercise using three different designs. The results can be interpreted as follows:

1. Design B

- Records the highest average muscle activity among the three designs.
- Indicates that exercising with Design B requires greater muscular effort.
- The box plot is positioned higher and concentrated at relatively elevated values.

2. Design A

- Demonstrates lower muscle activity compared to Design B.
- Shows a moderate distribution, with some outlier values (points below the box).
- This may suggest that the design is balanced and does not significantly strain the muscles.

3. Design C

- Falls between Designs A and B in terms of muscular effort.
- Contains some low outlier values, indicating exceptional cases of reduced muscle activity.
- Exhibits slightly greater variance than Design A.

Preliminary Conclusion:

- Design B requires higher muscular effort and may be suitable for endurance training.
- Design A exerts the least effort, making it potentially more appropriate for light exercises or special populations.
- The differences between the designs are visually evident and warrant statistical analysis (e.g., ANOVA) to confirm their significance.

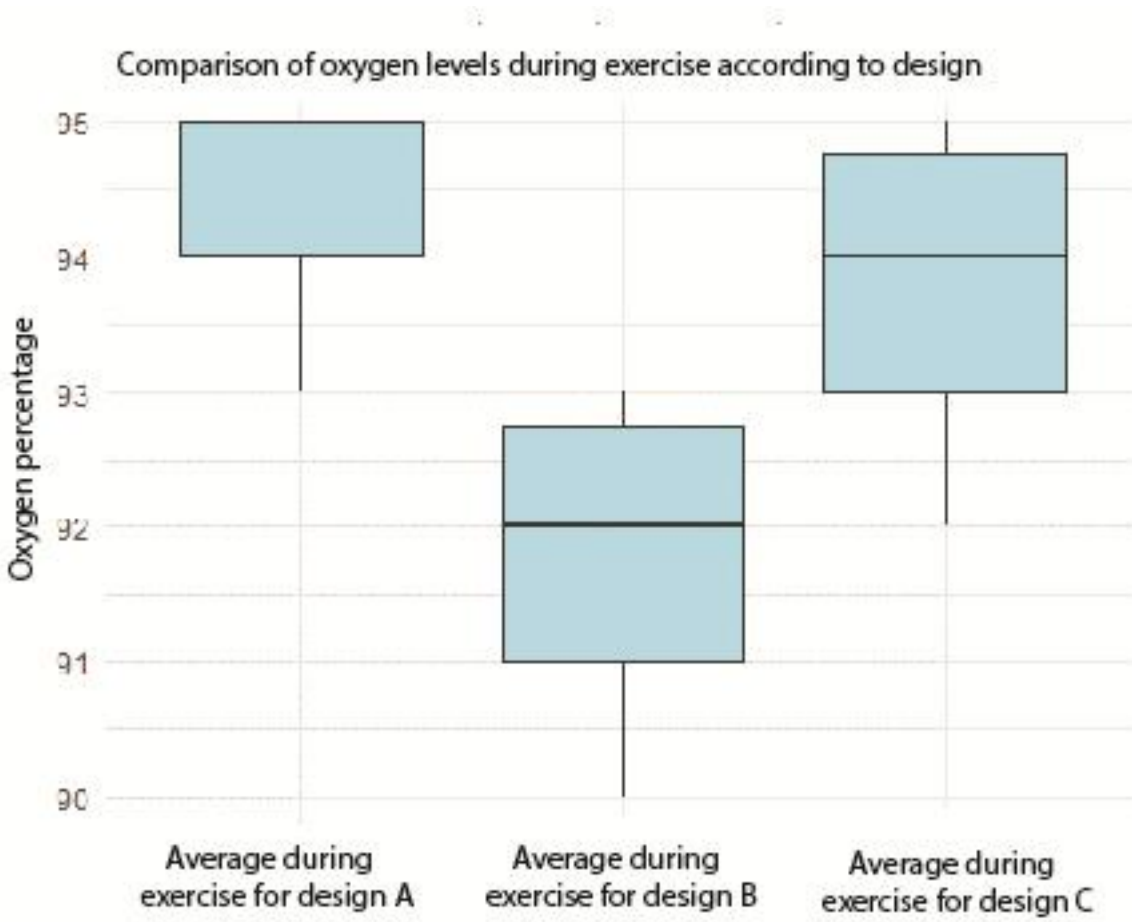

Fig (8). Comparison of oxygen levels during exercise according to the different exercise designs according to the design

The graph (2) illustrates the distribution of oxygen saturation levels during exercise using three different designs. The results can be interpreted as follows:

1. Design A

- Exhibits the highest oxygen saturation level during exercise.
- Most values are concentrated between 94% and 95%.
- This suggests that the design may help maintain stable respiration and blood oxygenation under exertion.

2. Design B

- Shows the lowest oxygen saturation rate among the three designs.
- Includes low values reaching approximately 90%.
- This may indicate greater physiological stress or a respiratory challenge during exercise with this design.

3. Design C

- Falls between Designs A and B.
- Displays a slightly wider distribution, though no clear outlier values are observed.
- It can be considered a design with moderate impact on oxygen saturation levels.

Preliminary Conclusion:

- Design A appears to be the most effective in maintaining blood oxygen saturation during exercise.
- Design B may lead to reduced oxygen saturation, making it a more physiologically demanding option.
- Design C offers a relatively balanced effect.

Overall Interpretation and Final Conclusion:

The comparative analysis of muscle activity (EMG) and oxygen saturation (SpO_2) across the three garment designs demonstrates the influence of fabric type and placement on physiological responses during exercise.

- **Design A**, fully constructed using **Far Infrared (FIR) functional fabric**, yielded the **lowest muscular effort** and the **highest oxygen saturation levels**. This suggests that FIR fabric may play a key role in **reducing fatigue** and **enhancing circulatory and respiratory efficiency** during physical activity. These results affirm the **performance-supporting potential of FIR**

textiles, especially for low to moderate intensity workouts or for users with special physical needs.

- **Design B**, made entirely from a **locally available standard sports fabric**, showed the **highest muscle activation** and the **lowest oxygen saturation**. These values reflect a **natural physiological response** without any performance enhancement, resulting in a **higher physical load**. This design may be more appropriate for high-effort or resistance-based training, where increased muscle engagement is desired.
- **Design C** featured a **hybrid structure**, combining **FIR fabric strategically placed over targeted muscle areas**, with the remainder of the garment constructed from the same local sports fabric used in Design B. The physiological data from this design were **intermediate**, showing reduced muscle strain and improved oxygen levels compared to Design B, though not reaching the performance levels of Design A. This outcome indicates that **partial integration of FIR fabric**, especially when concentrated over major muscle groups, can **positively influence physiological responses** during exercise.

Final Recommendation:

- **Full FIR integration (Design A)** is most effective for supporting **muscle efficiency and oxygen maintenance**, making it ideal for recovery, endurance, and functional training.
- **Standard sports fabric (Design B)** produces a **natural, unassisted physiological response**, suitable for higher-intensity or resistance training.
- **Targeted FIR placement (Design C)** provides a **balanced solution**, combining some of the benefits of functional textiles with the practicality of local materials.

5. Conclusion

The research concludes that the integration of FIR fabrics in sportswear can positively influence physiological performance during exercise. The fully FIR-integrated design significantly reduced muscle strain and maintained higher blood oxygen saturation compared to conventional sportswear. This suggests improved circulatory efficiency and reduced muscular fatigue. The hybrid design, with strategic FIR placement, also exhibited favorable results, supporting the idea that even partial integration can yield performance benefits. Thus, FIR textiles present a promising innovation in functional sportswear, especially for endurance training, recovery, and users with specific physiological needs. The findings support further development and adoption of FIR-based garments in athletic apparel industries.

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