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Thermoregulatory Comfort Properties of Sports Jersey Fabric: A Review

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ABSTRACT

This paper explores the thermoregulatory properties of sports jersey fabrics. This review aims to analyse the influence of material composition, fabric structures, and design features on thermal comfort and athletic performance. Investigation of natural and synthetic fibres, and recent innovations in regenerated and microfibres forms the foundation of the review. Key findings include the significant impact of synthetic fibres, particularly polyester, nylon, and spandex, enhancing performance through moisture-wicking properties. Knitted fabrics outperform woven structures in flexibility and moisture transport. Coolmax® and Tencel™ improve athlete comfort through moisture-wicking properties. Thermal comfort and moisture management improved by yarn combinations in multi-layer clothing systems. The review emphasizes the importance of design features that combine aesthetics and functionality, essential for enhancing athletic performance. Although the review covers material and structural factors, it lacks a thorough technical analysis of heat and moisture transfer mechanisms in various fabric structures and fibre blends. Comprehensive analysis may improve understanding of fabric engineering strategies to enhance thermoregulatory comfort. The paper discusses the evolution of sportswear design, multi-layer systems, performance, and comfort, enhanced temperature regulation. The review outlines current challenges, presenting perspectives for future advancements in sports jersey fabrics aiming to improve thermoregulatory performance across various environmental conditions.

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INTRODUCTION

Clothing comfort arises from a combination of individuals' psychological and physiological responses and the properties of materials, making objective evaluation challenging. These are influenced by clothing style, material, and psychological factors affecting the wearer's experience, acceptance, and performance (Xiaofei, 2021). Thus, subjective evaluation methods are often used to assess comfort levels (Tang et al., 2015). This relates to thermal comfort which refers to the psychological state in which individuals express satisfaction with the ambient temperature conditions and are evaluated by subjective assessment (American National Standards Institute [ANSI] & American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], 2013).

The clothing system consists of interacting components that impact the overall functionality and wear comfort sensation which comprises textiles (yarns, fibres, fabric properties, and physical parameters) and clothing fit, design, and openings (Raccuglia et al., 2018), both of which impact athlete performance. The sportswear industry has become one of the most innovative and highly advanced textile industries in enhancing comfort, focusing on materials that effectively transport heat and moisture, dry quickly, and offer good air and water permeability, lightweight, strong, and durable with low thermal resistance and high air permeability to ensure thermal comfort during workouts (Anandhakumar, 2021; Öner & Okur, 2013). This paper reviews the thermoregulatory comfort of sports jersey fabrics, discussing sports jersey materials, fabric qualities, design aspects, and the impact of thermoregulation on athletes' performance and comfort. It also addresses the challenges and limitations in meeting athletes' needs with current textiles.

Fibres for sportswear

Synthetic fibres such as polyester, nylon, spandex, and novel fibres dominate the sports textile market. Polyester is popular in sportswear due to its dimensional stability, smooth feel, and low cost although its low moisture absorption can lead to discomfort in hot and humid conditions (Özdil & Anand, 2014; Di Domenico et al., 2022). Nylon is lightweight and has high strength, softness, good durability, and outstanding wicking behaviour, but its low air permeability can trap heat (Kejkar & Dhore, 2019). Spandex (elastane) like Lycra known for its elasticity and support, is also common in sportswear. However, high humidity and heat can hinder breathability and comfort (Ahmad et al., 2023). Innovations in textile technology have led to blends of natural and synthetic fibres, enhancing functionality. Regenerated fibres, such as Tencel ™ (lyocell), are absorbent and strong, outperforming cotton in abrasion resistance (Özdil & Anand, 2014). Modal rayon, developed to improve wet strength, absorbs moisture better than viscose but less than cotton (Islam et al., 2023). Microfibres, with their ultrafine structure, offer excellent breathability and moisture-wicking properties (Ahmad et al., 2023). Coolmax® is a specialized polyester that efficiently transports moisture away from the skin (Kejkar & Dhore, 2019).

Table 1 shows the comparison of materials used in sportswear. Several studies incorporate synthetic fibres with various fibre blend compositions for sportswear designs (Ziemele et al., 2018; Fan et al., 2020; Fan & Tsang, 2008; Sun et al., 2015; Özkan & Kaplangiray, 2020; Ahmad & Jamshaıd, 2019; Lam et al., 2020; Choudhary & Ramratan, 2020). Blending various fibres can combine the most desirable features. Polyester and polyamide/elastane blends offer comfort benefits due to low water vapour permeability (Ziemele et al., 2018). Nike and Adidas have developed fabrics with enhanced air permeability, with Nike's perforated designs promoting better airflow compared to Laishilong and Columbia (Fan et al., 2020). Research using a sweating manikin assessed comfort sensations related to polyester and nylon fabrics (Fan, & Tsang, 2008). A novel ventilated clothing was invented to reduce evaporative resistance and improve wearer comfort during exercise (Sun et al., 2015). Tencel™ and polyester mesh were recommended for athlete clothing for their air permeability and moisture management (Özkan & Kaplangiray, 2020). Studies also analysed the moisture-wicking properties of modal and micro-polyester for warm-weather sportswear (Ahmad & Jamshaıd, 2019). Nike samples demonstrated maximum airflow and comfort related to fibre content (Lam et al., 2020). Choudhary and Ramratan (2020) investigated the influence of yarn and knit

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structure on moisture management of sportswear fabric using 100% micro polyester, 100% texturized polyester, and 96% core spun polyester/4% elastane. Micro polyester features a low denier, while texturized polyester involves the modification of the structure of continuous filament yarn with curls, waviness, crimp, and wrinkles (Ramachandran et al., 2009; Borse et al., 2018). The corespun yarn consists of a sheath-core yarn formed by twisting fibres as a sheath around the core of the yarn (Hari, 2020). The effective moisture management of micropolyester highlights the importance of structural porosity and microchannels (Choudhary & Ramratan, 2020). Overall, the material selection in sportswear is crucial for optimizing comfort and moisture management in sportswear, with advancements in design contributing to improved performance.

Table 1. Materials used in sportswear

Fibre content	Fabric structure	Findings	Ref.
1. 100% polyester (Coolmax®) 2. 82% polyamide/18% elastane	Not specified	- Low water vapour permeability shows a good sense of comfort	(Ziemele et al., 2018)
1. 85% polyester/15% cotton (Nike) 2. Front: 61% polyester recycled/39% polyester; back: 51% polyester/49% polyester recycled (Adidas) 3. 100% polyester (Laishilong) 4. Shell face: 100% polyester; side panel: 86% polyester/14% elastane (Columbia)	1. Single Jersey (Nike and Adidas) 2. Double jersey (Laishilong and Columbia)	- Sample with holes (Nike) showed the best performance with low air permeability. - Both Nike and Adidas perform better air permeability than Laishilong and Columbia	(Fan et al., 2020)
1. 100% polyester (top), 100% nylon (bottom) (set 1) 2. 100 % Polyester (top and bottom (set 2, 3, 4, and 5))	Not specified	- Comfort sensations before exercising related to tactile sensations. - Comfort sensations after exercising related to the moisture vapour resistance of clothing and the percentage of moisture accumulation within clothing measured from sweating manikin.	(Fan, & Tsang, 2008)
20% nylon/ 80% polyester	1. Fabric 1: single jersey 2. Fabric 2: single jersey with spacer 3. Fabric 3: mesh opening with spacer	- The ventilated design has lower evaporative resistance and moisture permeability index. - The ventilated design reduced the variation in skin temperature and humidity. - The wearer felt more comfortable with the novel ventilation-design garment during exercise.	(Sun et al., 2015)
1. 100% cotton 2. 50% cotton/50% polyester 3. 91% textured polyester/9% spandex 4. 98% textured polyester/2% polyester trilobal 5. 100% Tencel™ 6. 94.5% modal/5.5% spandex 7. 92.5% textured polyester/7.5% spandex	1. Single jersey 2. Mesh (weft knit)	- 100% Tencel™ fabric has the highest air permeability and OMMC. - 98% textured polyester/2% polyester trilobal fabric with mesh fabric structure has low water vapour resistance. - Tencel™ single jersey and polyester mesh knitted fabric, or combinations can be preferred for athlete clothes.	(Özkan & Kaplangiray, 2020)
1. 62% cotton/33% polyester/5% spandex 2. 62% cotton/33% micro polyester/5% spandex 3. 62% modal/33% polyester/5% spandex 4. 62% modal/33% micro polyester/5% spandex	Single jersey plaited fabrics	- Modal and micro polyester materials wick moisture. - Air permeability and thermal conductivity increased with high evaporation and low dry rate. - Modal fibres with micro polyester single jersey fabrics have greater air permeability, overall moisture management properties,	(Ahmad & Jamshaıd, 2019)

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Fibre content	Fabric structure	Findings	Ref.
		and pilling properties for warmer climate sportswear.	
1. 86% terylene/14% elastane (OUDIKE) 2. 89% polyester/ 11% spandex (unknown brand) 3. 100% Polyester (NIKE), 84% polyester/16% spandex (body), 92% polyester/8% spandex (back) (NIKE)	1. Single knit stitch 2. Tuck and knit stitch	- Nike sportswear had maximum air permeability that allowed more airflow and comfort. - OUDIKE samples had the lowest air permeability. - The fibre content and fabric impact air permeability.	(Lam et al., 2020)
1. 100% micro polyester 2. 100% texturized polyester 3. 96% core spun polyester/4% elastane	1. Weft knit single jersey 2. Rib 3. Interlock	- Micro polyester plain single jersey showed high comfort performance. - Dry rate, water vapour permeability, and vertical wicking are correlated with moisture management, structure porosity, and microchannels for water transportation.	(Choudhary & Ramratan, 2020)

Note: Brackets in the fibre content column represent the brand name.

Microfibres

Microfibres made from polyester and nylon have high linear densities of less than 0.4 dtex and offer high porosity, enhancing moisture release and temperature regulation (Turukmane & Daberao, 2023). Their excellent softness, lightweight, high dimensional stability, high absorbent surface, smooth hand, and superior breathability contribute to comfort (Kale, 2010). Compact fabrics from microfibre yarn increase capillary action and thermophysiological control (Kejkar & Dhore, 2019).

Research on double-face weft knitted sports clothing with a microfibre top layer and bamboo bottom showed effective moisture transfer, keeping wearers dry (Thangamuthu & Pandurangan, 2022). Testing on three-layered textiles, combining cotton, polyester microfibre, and elastane, revealed that cotton outperformed polyester and elastane in wick ability and thermal properties (Gopalakrishnan & Ramachandran, 2016). Nanoparticles have been used to enhance the functionality of polyester microfibre single jersey fabrics (Elgory et al., 2020). Typically, normal denier fabrics exhibit better drapeability, wicking, and absorbency compared to microdenier fabrics, while both have similar abrasion resistance (Srinivasan et al., 2007). The tuck stitch in layered knitted fabrics has influenced thermal comfort, as shown in bi-layer constructions with microfibre polyester and modal yarn (Senthilkumar & Suganthi, 2019). These compositions improved subjective comfort and moisture control, providing enhanced thermal comfort for athletes, particularly in shuttle badminton players (Suganthi & Senthilkumar, 2018b).

Fabric structures

A wide variety of fabrics for sportswear differ in air entrapment, pore size, volume, and surface features, all affecting heat and moisture transmission (Kanakaraj & Ramachandran, 2015). Knitted textiles provide advantages over woven fabrics due to their flexibility and stretchability, enabling free movement and efficient moisture transfer (Stojanović & Geršak, 2019; Kejkar & Dhore, 2019). Advances in fabric construction and yarn combinations make knitted fabrics ideal for active sportswear (Uttam, 2013).

Knitting is categorized into two types: weft knitting and warp knitting. Weft knitting creates loops across the fabric's width, while warp knitting forms loops along its length. This classification is based on the direction of yarn movement to fabric formation. The main weft-knitted structures are plain (single jersey), rib, interlock, and purl, as shown in Fig 1. The single jersey features V-shaped stitches on one side and semicircles on the other. It is made with a single set of needles but unravels easily due to its unbalanced nature. Rib structures use two sets of needles, providing more elasticity and warmth while lying flat. Purl fabrics involve loops intermeshed in both directions, using a single set of needles. Interlock fabrics are constructed with two needles, creating a stable, reversible fabric that requires finer yarn, making it thicker

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and more expensive than rib structures (Gong & Ozgen, 2018; Wilson, 2001). Single jersey fabrics are frequently used for various applications, including t-shirts and sweaters. Rib fabrics are used in applications requiring significant elasticity, such as the cuffs and collars of t-shirts and garments designed in multiple sizes. Interlock fabrics are used for pants and sportswear that need high opacity and thickness (Dassanayaka et al., 2024). Purl fabrics are used for children's clothing, knitwear, and heavy outerwear (Ray, 2012).

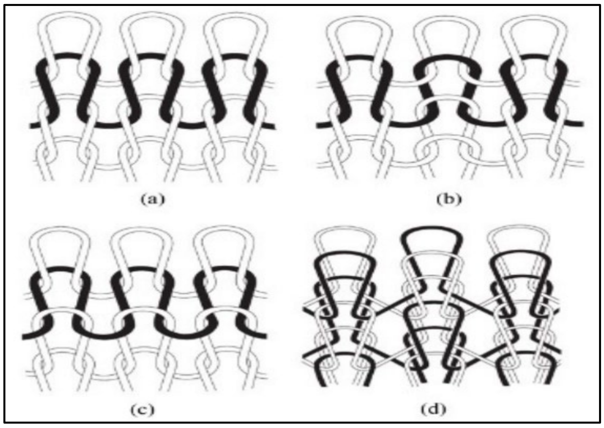

Fig. 1. Basic weft-knit structures (a) single jersey, (b) rib, (c) purl, and (d) interlock (Wilson, 2001).

The demand for flexible, tight-fitting activewear has increased the use of weft-knit materials (Watkins & Dunne, 2015). Researchers have analysed how different knit structures impact the thermophysiological properties of knitted fabrics (Elkholy, 2018; Onofrei et al., 2011; Özkan & Kaplangiray, 2020; Choudhary & Ramratan, 2020; Hoque et al., 2022; Selli & Turhan, 2017; Mishra et al., 2021; Ahmad et al., 2023; Chakroun et al., 2021; Kaplan & Akgünoğlu, 2021). Table 2 compares fabric structures related to comfort, showing that weft-knitted fabrics like single jersey, interlock, and rib influence sportswear comfort. Fabric structures significantly affect clothing comfort and moisture transport. Open mesh fabrics excel in T-shirt comfort (Elkholy, 2018), while outlast fabrics are favoured for their high air permeability and low thermal resistance (Onofrei et al., 2011). Textured polyester with finer yarns also offers better air permeability (Özkan & Kaplangiray, 2020). Plain single jerseys are optimal for moisture management, effectively absorbing and transporting moisture (Choudhary & Ramratan, 2020; Hoque et al., 2022). Rib fabrics provide higher air permeability, which increases with yarn count but decreases with mass (Selli & Turhan, 2017). Single jersey is suitable for hot weather, single pique is ideal for summer, and double Lacoste is better for colder conditions (Mishra et al., 2021).

Single jersey has the least air permeability, whereas plain pique shows the most (Ahmad et al., 2023). Combining tuck and knit stitches enhances permeability, while tight materials like jersey crepe polyester improve comfort by resisting air and water vapour (Chakroun et al., 2021). Polycolon® polypropylene used in piquet structures for sports socks offers superior liquid absorption in high moisture and temperature areas prone to blisters (Kaplan & Akgünoğlu, 2021).

Table 2. Comparison of fabric structures

Fabric structure	Material	Findings	Ref.
- Single jersey, interlock, rib - Ventilation structure: flat mesh, open holo mesh, closed holo micro mesh, open holo micro mesh	Polyester Polyester	- Ventilation, properties, and fabric structures contribute to the T-shirt comfort. - Open mech structure fabric: best air, heat, water vapour, wettability, wicking, and drying properties.	(Elkholy, 2018)

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Fabric structure	Material	Findings	Ref.
- Nine knitted structures combining plain, tuck, rib, and float stitches	30% viscose/ 70% cotton (Outlast®), and Dacron (Coolmax®)	- Outlast fabrics: low thermal resistance, high thermal conductivity, absorptivity, water vapour permeability. - Single jersey, rib, and double one-needle floats with high air permeability and low thermal resistance.	(Onofrei et al., 2011)
- Mesh rib, mesh	Textured polyester	- Air permeability increases with yarn fineness and loop length. - Single yarn mesh rib knit fabric has the highest air permeability. - Single yarn mesh rib knit fabrics absorb higher and spread faster than two-ply knitted fabrics.	(Özkan & Kaplangiray, 2020)
- Single jersey, 1 x 1 rib, interlock	100% micro-polyester, 100% polyester, 96% polyester/ 4% lycra	- Plain single jersey fabric, the most porous structure shows the best moisture management.	(Choudhary & Ramratan, 2020)
- Weft knit from plain single jersey, single lacoste, double lacoste	100% polyester, 100% cotton, 100% viscose	- Plain single jersey fabric: the highest wicking. - Single Lacoste and double Lacoste fabric: a downward tendency except for 100% cotton single Lacoste fabric.	(Hoque et al., 2022)
- Single jersey, 1x1 rib, 2x1 rib	100% combed cotton	- Rib fabrics: higher air permeability than single jersey fabrics due to dyeing, finishing, and machine gauge. - Single jersey fabrics' air permeability increases with yarn count but decreases with mass. - Moisture management properties of single jersey and rib fabrics decrease as the fabric mass increases.	(Selli & Turhan, 2017)
- Single jersey, single lacoste, double lacoste, single pique, double pique	100% combed cotton	- Single jersey is suitable for hot weather high-intensity exercise due to its lowest thermal resistance and highest RWVP%. - Single pique is ideal for summer. Allows cold air to penetrate, cooling the body and evaporating sweat. - Double Lacoste offers superior thermal resistance, air permeability, and moisture management capacity for low physical activity in cold weather.	(Mishra et al., 2021)
- Single jersey, single jersey derivatives (single lacoste, double lacoste, honeycomb, plain pique)	100% cotton	- Single jersey has the lowest air permeability and plain pique has the highest air permeability. - Knit-tuck stitches combination enhances air permeability. - Plain pique has the highest value of air permeability due to the combination of tuck and knits stitch. - The optimal airflow is achieved with an alternating combination of tuck and knit stitch.	(Ahmad et al., 2023)
- Jersey crepe, honeycomb, mesh	Wool merino, 100% polyester, 100% polyamide, 57% polyamide/ 43% polyester, COCONA® polyester	- Tight fabrics have low air permeability. - Knitted fabric with greater weight per unit area and thickness resists air and water vapour. - Jersey crepe polyester COCONA® shows the best comfort performance.	(Chakroun et al., 2021)

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Fabric structure	Material	Findings	Ref.
- Single jersey, piquet, terry	1. 100% polyester 2. 78% polyester/ 15% polyamide/ 7% elastane 3. 100% Thermocool® 4. 78% Thermocool®/ 15% polyamide/ 7% elastane 5. 100% polypropylene 6. 74% polypropylene/ 17% polyamide/ 9% elastane 7. 100% Polycolon® 8. 74% Polycolon®/ 17% polyamide/ 9% elastane	- Polycolon® polypropylene in piquet structure performs the best in sports socks due to lightweight, and permeable fabric. - Polyester excelled in liquid absorption in piquet and terry structures. - Polycolon® in piquet structure is recommended for areas prone to blisters during running in high moisture and temperature conditions.	(Kaplan & Akgünoğlu, 2021)

Multi-layer clothing system in sportswear

Sportswear has evolved from being worn against the skin to outerwear, performance, and aesthetics enhancement (Gorea et al., 2021). Synthetic fibres contributed to transforming basic sportswear into technologically advanced sportswear improving properties such as wicking, fast drying, anti-odour, UV blocking, water repellency, breathability, and wind-chill resistance (Ahmad et al., 2023; Jhanji, 2021; Kejkar & Dhore, 2019).

Plenty of research has focused on multi-layer systems to enhance a superior level of comfort in sportswear (Stojanović & Geršak, 2019; Özdil & Anand, 2014). Each layer serves a unique purpose; the layer in direct contact with the skin removes perspiration by wicking, while the outer layer facilitates evaporation, keeping the skin dry and regulating body temperature (Stojanović & Geršak, 2019). Thermal comfort can be achieved by layered knitted structures with hydrophobic and hydrophilic layers. The inner layer is constructed from hydrophobic or synthetic filament yarns which have good capillary action, and the outer layer is made up of hydrophilic yarn which has good moisture absorbency (Suganthi & Senthilkumar, 2018a) as shown in Fig 2. Polyester, nylon, acrylic, and polypropylene are used in the inner layer due to their moisture transfer capabilities. The outer layer consists of cotton, wool, viscose rayon, or their combinations for effective moisture absorption (Özdil & Anand, 2014).

Studies on bi-layer knitted fabrics have shown that specific yarn combinations, such as microfibre polyester for the inner layer and modal for the outer layer, provide excellent moisture management (Suganthi & Senthilkumar, 2018b). Research on various yarn types indicates that combinations like microdenier polyester exhibit superior absorption and moisture transport (Udaya Krithika et al., 2021). Multi-layered weft-knitted fabrics with wool outer layers and polyester inner layers have demonstrated effective thermal insulation (Buzaite et al., 2021). Bi-layer fabrics with polypropylene and modal have shown higher air and moisture permeability, making them ideal for sportswear (Suganthi et al., 2017).

Investigations into different blended structures, including polyester-wool and polyester-modal, highlight the latter's suitability for activewear due to its moisture management and thermal properties (Soundri & Kumar, 2023). Additionally, trilayer fabrics combining bamboo, microdenier polyester, and cotton have shown excellent moisture management and comfort (Kalaiselvi et al., 2022). Overall, the composition and structure of bi-layer knitted fabrics significantly influence thermal comfort, moisture management, and dynamic cooling capabilities, particularly with materials like cool-touch polyester and nylon (Yang et al., 2021).

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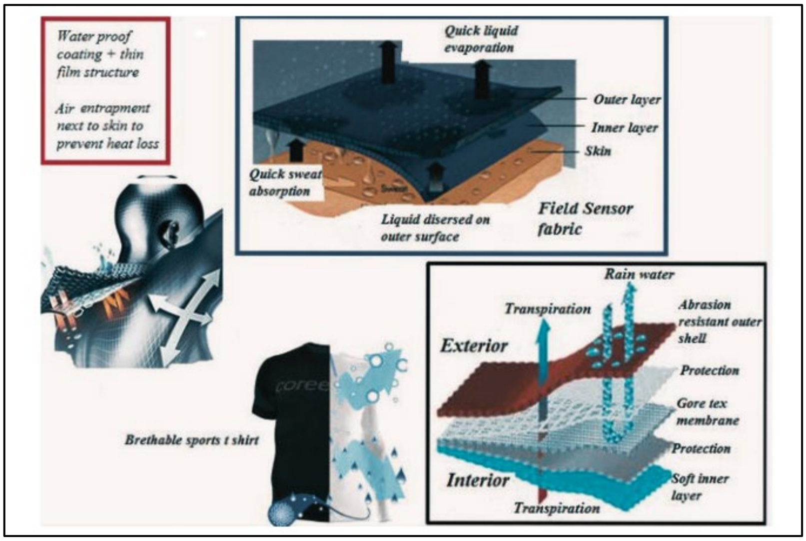

Fig. 2. Multi-layer fabric system (Jhanji, 2021).

Based on the findings in the review, the qualitative table and radar chart were developed to provide a comparison of the performance attributes of various sports jersey fabrics. Table 3 compares the performance of sports jersey fabrics, including polyester, nylon, spandex, Tencel™, Coolmax®, and microfibres, across properties such as moisture management, breathability, thermal comfort, durability, and flexibility. The ratings follow a scale from 1 to 5, where 1 is poor and 5 is excellent. Fig 3 shows a radar chart of key performance properties. Tencel™ and Coolmax® emerge as the top performing materials, excelling in moisture management, breathability, and thermal comfort, while also exhibiting good durability. Microfibres demonstrate versatility with high breathability, solid moisture management, and reasonable thermal comfort and durability. Polyester and nylon offer strong moisture management and durability but less breathability and thermal comfort. Spandex stands out for its flexibility and fit but has lower ratings in moisture management and durability compared to the other fabrics. This comparative analysis can guide the informed selection of appropriate materials to optimize athletic performance and wearer comfort for different sports applications and environmental conditions.

Table 3. Comparison of performance attributes of sports jersey fabrics

Fabric type	Moisture management	Breathability	Thermal comfort	Durability	Flexibility
Polyester	4	3	3	4	3
Nylon	4	2	3	5	3
Spandex	3	3	4	3	5
Tencel™	5	4	5	4	4
Coolmax®	5	5	4	4	4
Microfibres	5	5	4	4	4

Design features of sports jerseys

Generally, sports jerseys symbolise teams, promoting a sense of loyalty and belonging among their supporters. Their design has evolved significantly to meet consumer demands, influenced by fashion trends and performance innovations. For major events like the World Cup, manufacturers such as Adidas, Nike, and Puma conduct extensive research to create unique designs that comply with FIFA guidelines, balancing aesthetics with functional features like ventilation and sweat management (Sokolowski, 2018).

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Technological advancements have introduced moisture-wicking, lightweight, and breathable materials that enhance athletic performance. Incorporating mesh improves ventilation, with innovations combining spacer and mesh structures tested for superior thermal comfort and moisture permeability (Sun et al., 2015).

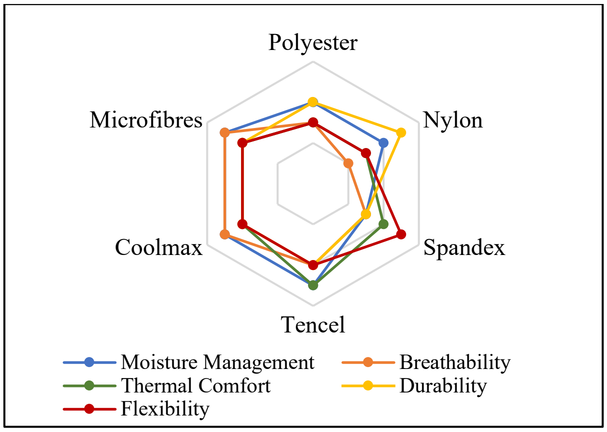

Fig. 3. Performance comparison of sports jersey fabrics.

Sports jersey design features focus on fit, material technology, colour psychology, and functional integration. The fit of a sports jersey is crucial for optimal performance, improves movement, and reduces injury risk (McLean et al., 2018; Wintershoven et al., 2023). Custom-designed vests for wearable technologies such as accelerometers provide accurate data movement (McLean et al., 2018; Alonso et al., 2020). The jerseys design also considers athletes' physiological needs ensuring they can perform without restrictions (Bogers et al., 2017). Advancements in fabric technology have led to jerseys that offer superior moisture management, breathability, and durability. Nylon, polyester, and spandex are widely used to improve fabric moisture-wicking and comfort (Gorea & Ellis, 2020; El Tantawy et al., 2020). Seamless knitted materials increase blood circulation and minimize muscle fatigue during strenuous physical exercise (Gorea & Ellis, 2020).

Eco-friendly materials are increasingly popular as consumers demand sustainability (El Tantawy et al., 2020). Adidas introduced Adizero and Climachill fabrics during major tournaments, while Nike's VaporKnit technology was adopted for the 2018 World Cup (Bouredji et al., 2020). Jersey colours influence player performance and fan engagement, with colours like red potentially increasing aggression (Dreiskaemper et al., 2013). Aesthetically, colours are crucial for team identity, visibility, and perception during gameplay (Garcia, 2023; Mentzel et al., 2019). Modern jerseys also integrate technology for performance tracking and safety, embedding global positioning systems (GPS) and accelerometers to monitor player movements and physiological responses in real-time (Nicolella et al., 2018; Alonso et al., 2020). This data allows coaches to tailor training and improve athlete conditioning while maintaining comfort and mobility (Lehra et al., 2022; Veske et al., 2022). Overall, advancements in jersey design enhance athletic performance and meet the visual and psychological needs of athletes and fans.

Performance and comfort

When designing sports jerseys, it is essential to consider heat regulation, performance, and comfort. Sweating helps maintain a core temperature of 37 °C (98 °F) by balancing metabolic heat production and loss (Di Domenico et al., 2022). Thermoregulatory comfort is the thermal satisfaction experienced by individuals in response to their thermal environment. Thermoregulatory comfort influenced by physiological, environmental, and behavioural factors is vital for maintaining thermal equilibrium. The

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body's heat balance is significantly affected by air temperature, humidity, clothing insulation, and individual metabolic rates (Riaz & Mahmood, 2021; Ramli et al., 2018; Peng & Hsieh, 2023).

A wear trial examined how different garments affected athletes' thermophysiological and psychological comfort. Tencel™ single jersey and polyester mesh fabrics with low thermal resistance and high air permeability, improved comfort by lowering microclimate humidity and temperature, reducing training effort (Özkan et al., 2023). The impact of polyester jerseys on cyclists in hot conditions showed enhanced thermal comfort and heat dissipation (Gonzales et al., 2011). Another study found that tight-fit polyester sportswear increased skin wetness and thermal sensation, while cotton lost less heat during warm, humid exercise (Wibowo et al., 2018). Research on national-level athletes during prolonged running indicated that various fabric types did not significantly affect running speed or physiological heat strain (Ioannou et al., 2024). American football players demonstrated increased core temperatures during exercise, highlighting the risk of exertional heat illness (EHI) when wearing complete outfits (Leites et al., 2023).

Sweat distribution patterns were applied to design three body-mapping T-shirts and compared to a conventional T-shirt. The body-mapped T-shirt designed using sweat distribution patterns showed significant improvements in skin temperature and microclimate over conventional T-shirts, enhancing thermal comfort and running performance. The open-knit fabric had higher water vapour and air permeability, allowing quicker heat dissipation and normal skin temperature (Varadaraju & Srinivasan, 2019).

A comparison of cycling performance between synthetic fabrics (60% polyester / 40% nylon) and cotton fabrics found that synthetic materials provided better cooling, comfort, and lower skin temperature, improving overall performance during a 20-km time trial (Ferguson et al., 2022). The relationship between fabric characteristics and thermoregulatory comfort is important, since it affects both physical performance and the risk of heat-related illnesses. Enhancing understanding of the interaction between different materials and the body's thermoregulation enables athletes to perform in various environmental conditions.

CONCLUSION AND FUTURE REMARKS

The sports textiles market is growing due to increased public engagement in sports and higher consumption of sports items. Performance relies on effective moisture management, air permeability, and thermal insulation, which can be challenging to achieve in high-performance textiles. Key factors include raw materials, fibre type, yarn structure, and design. Consumer perception significantly influences the acceptance of sports jerseys, particularly regarding thermoregulatory comfort. As comfort and performance become priorities in purchasing decisions, understanding consumer experiences with fabrics like Coolmax® and microfibres is essential. Surveys can provide valuable feedback to help manufacturers meet consumer needs in tailoring products effectively.

Future research should prioritize sustainable materials, focusing on the environmental impacts of fabric production and waste management. Additionally, exploring smart textile technologies can enhance the functionality and comfort of sports jerseys. Investigating new materials and optimizing fabric structures for various weather conditions will advance sportswear design. It is important to study the influence of clothing fit on thermal comfort and performance, as consumers seek both aesthetic appeal and functionality. This review lays the groundwork for future research on eco-friendly materials, the environmental effects of sportswear, and innovative technologies for better temperature regulation in sports jerseys. Further exploration of socio-cultural factors in sports jersey design can lead to more inclusive and athlete-focused strategies.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: **study conception and design**: Wan Syazehan Ruznan; **data collection**: Suraya Ahmad Suhaimi; **analysis and interpretation of results**: Suraya Ahmad Suhaimi, Wan Syazehan Ruznan, Raja Nurul Jannat Raja Hussain; **draft manuscript preparation**: Suraya Ahmad Suhaimi, Wan Syazehan Ruznan, Mohd Rozi Ahmad, Mohd Azlin Mohd Nor. All authors reviewed the results and approved the final version of the manuscript.

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