textiles

Review

Factors Affecting the Sweat-Drying Performance of Active Sportswear—A Review

Surya Nasrin [1], Sumit Mandal [1,*], MD. Momtaz Islam [1], Adriana Petrova [1], Robert J. Agnew [2] and Lynn M. Boorady [1]

[1] Department of Design and Merchandising, Oklahoma State University, Stillwater, OK 74078, USA; surya.nasrin@okstate.edu (S.N.); momtaz.islam@okstate.edu (M.M.I.); adriana.petrova@okstate.edu (A.P.); lynn.m.boorady@okstate.edu (L.M.B.)
[2] Fire Protection and Safety Engineering Technology Program, Oklahoma State University, Stillwater, OK 74078, USA; rob.agnew@okstate.edu
* Correspondence: sumit.mandal@okstate.edu; Tel.: +1-(405)-744-3819

Abstract: Quick drying is one of the most crucial factors in the comfort and performance of active sportswear clothing. It helps to keep the wearer dry and comfortable by effectively wicking away sweat and moisture from the body. In the light of this, a substantial number of previous researchers have identified fabric properties and types that have a significant impact on fabric drying performance. Studies have also been conducted to examine the impact of fabric drying on human physiology during sports-related activities. However, there are still some technical knowledge gaps in the existing literature related to the drying performance of active sportswear fabrics. This review article provides a critical analysis of the literature on the impact of various fabric attributes as well as the physiological and environmental factors on moisture management and drying performance. The key issues in this field are determined so that future research can be directed and this scientific field can advance in order to improve the overall performance of active sportswear fabrics.

Keywords: active sportswear; fabric drying; moisture management; fabric properties; human physiology; environmental factors

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1. Introduction

Sportswear has become a popular type of clothing category worldwide due to its thermo-physiological comfort. In the early 1900s, sportswear design was separated from general fashion design due to its practical function and uniform aesthetic separating one sport from another. In the past fifty years or more, sportswear has become a driving force for new fashion trends and textile innovation [1]. In recent years, the demand for sportswear has increased globally. In 2020, the value of the global and US sportswear markets was estimated at approximately \$161 billion and \$73 billion (US dollars), respectively [2]. With the new advancements in textile technologies and changes in fashion and apparel worldwide, the consumer's choice depends not only on the appearance but also on the comfort properties of the fabric [3–5]. Hence, the textile industries have been concentrating their efforts on rethinking the concept of clothing through the application of innovative technologies and functional materials [6].

According to the *Cambridge Dictionary*, sportswear is clothing that is worn for sports or other physical activities or it is casual clothing that is made to be comfortable [7]. In contrast, the *American Heritage Dictionary of the English Language* says that sportswear is day and evening styles with different levels of formality that show a casual attitude, while still being appropriate for many business and social situations. It can be clothes made for sports-related activities as well as clothes that people wear to enjoy their leisure time [8]. Another study defined activewear as clothing that is made to meet the needs of the person wearing it while they work out [9]. For this review paper, the term "active sportswear" was used to represent the clothing that can be used during exercise as well as any sports-related activities where sweat drying is critical for fabric performance.

Researchers have found that the comfortability of an active sportswear fabric depends on its drying performance [10–12], which is critical for athletes to maintain body heat equilibrium [13–16]. The normal temperature of the human body is 37 °C [11,17], which rises during any physical exercise due to a higher metabolism rate [16]. Human perspiration starts when the skin temperature is equal to the core temperature of 37 °C [18]. A fabric with the ability to dry quickly can provide better thermal comfort to the wearer by transferring the sweat to the ambient environment [19,20].

Some of the desirable attributes of functional active sportswear include air permeability, moisture absorption, durability, light weight, and smooth texture [21,22]. The two most crucial features of an active sportswear fabric are its ability to transfer/transmit sweat and dry quickly [23,24]. Consumers usually wear active sportswear during any sport or exercise that causes them to sweat a lot [25], and the moisture from this sweat increases the wearer's discomfort [26]. As a result, the comfortability of active sportswear mostly depends on its ability to transmit this sweat away from the skin [27]. The way sweat transmits through a fabric depends on many of its properties, such as moisture management, air permeability, surface texture, and different physical properties, including thickness, weight, and yarn counts, among others. All these properties play a role in transporting sweat vapor from the skin to the outside atmosphere [27].

The drying performance of a fabric depends on the fiber types [28,29] and other physical properties [30–32]. It has been found that different fibers, yarns, and structural compositions in the fabric could lead to varied levels of drying by controlling the water absorption, wicking, and water vapor transfer capabilities. Both natural and synthetic fibers are currently used for active sportswear fabric [28]. However, synthetic active sportswear performs more effectively at maintaining the body temperature during exercise due to its high-wicking properties [33,34]. Nylon, polyester, and spandex are the most preferred materials for active sportswear because of their excellent moisture transport properties; however, some other types of synthetic fabrics could also be used [35]. A study found that the ability of a certain fabric to transfer sweat varies depending on the amount of sweat volume [36]. The drying rate is also affected by the velocity of the surrounding air [37]. Additionally, fabric structure has a significant impact on moisture transport [30–32]. Though different types of fabric structures, including knitted, woven, and non-woven fabrics, can be used in active sportswear, knitted fabrics have become popular for active sportswear because they are stretchy and wrinkle resistant and fit close to the body [28,38–41]. Knitted fabrics also have high air permeability when compared to other types of fabrics, making them breathable and susceptible to airflow [42].

The ability of a fabric to dry depends on how much the wearer sweats and the surrounding factors, such as wind speed, relative humidity, and temperature. As a result, to figure out how well a fabric dries, it is important to know how much sweating occurs during different types of sports or exercises. On average, a human body sweats around 60 mL of water vapor per hour when at rest under ambient conditions [11]. Moderate physical exercise, such as walking, will boost the amount to approximately 450 mL per hour after a few hours. When participating in sports, such as tennis or cycling, the metabolic heat increases six times and perspiration increases fourteen times (840 mL). During sweating, the human body's sweat is mostly attached to the surface of the clothing by adsorption [11]. The rest of the sweat drips, vaporizes, and stays in the microclimate. The sweat accumulates between the clothing and the body, increasing the body temperature. As a result, the human body begins to sweat more heavily [11].

In order to provide a better environment for athletes, it is essential that the fabrics used in active sportswear transmit the sweat away from the wearer's skin as soon as they adsorb the sweat [43]. Fabric drying occurs when the sweat evaporates into vapor, which then spreads out into the air. It involves two sequential processes of wetting and wicking [44]. Wetting is the initial process, where liquid spreads into the fabric by replacing the air interface [11,25,44]. Wicking is the fabric's capillary force, which determines how fast it can transfer the adsorbed sweat to the outer surface [11]. The process of evaporation is also important, as it helps transfer the sweat from the clothing's outer surface to the environment by mass diffusion. The temperature of sweat water in the fabric, air humidity, and airflow rate all play a role in how quickly sweat water molecules break apart and evaporate [45].

Given the aforementioned circumstances, a number of researchers have investigated the moisture management and drying processes of sports materials. The studies have identified several fabric properties that significantly impact the fabric's drying and moisture management performance. Moreover, several researchers have investigated the performance of different types of knitted active sportswear fabrics based on their moisture transfer abilities. In this paper, the effect of fabric properties on sweat drying and the performance of different types of active sportswear fabrics are thoroughly reviewed and critiqued to identify the gaps in existing research. This study would be a comprehensive resource to investigate different kinds of active sportswear fabrics and how their properties can help with managing moisture and drying at a quicker rate.

2. Review of the Literature

2.1. Method of Literature Search

A systematic literature review was chosen as the best way to bring together information from past studies and set the stage for future research. This was done to find research gaps in the current active sportswear fabric literature related to moisture management and drying performance and to make suggestions for future research. A systematic literature review is based on a repeatable, scientific, and clear process of finding, evaluating, and making sense of a body of existing literature. The validity of the review depends on how easily the steps can be repeated [46]. This study used a systematic literature review to examine the academic literature on moisture management and drying performance of active sportswear fabrics. Reviewing the articles in a systematic way reduces possible biases, make the results more reliable, and increases the value of the literature review as a whole [46].

The search process involved selecting two databases, those on the university library website and ProQuest, to identify a broad range of publications. Both databases were searched using two groups of keywords: ("properties" or "comfortability" or "moisture management" or "drying" or "air permeability" or "surface friction" or "human" or "environment") and ("clothing" or "apparel" or "activewear" or "sportswear" or "fabric"). These keywords were selected based on an initial overall literature review of active sportswear. From the initial review, some of the important aspects of active sportswear were identified. The keywords were selected in such a way that this review could include most of the critical issues that are related to active sportswear. The range of years was selected from 1955 to 2022, and only English language journals were selected for review. The university library website produced 11,490 results, and ProQuest (dissertations and theses only) produced 6346 results. The keywords were then modified to limit the search results. The updated keywords were ("properties" or "moisture management" or "drying" or "air permeability" or "surface friction" or "human" or "environment") and ("activewear" or "sportswear" or "fabric"). The updated keywords resulted in 7129 and 3820 results, respectively. Based on the titles and then the abstracts reviewed, a total of 80 articles were identified to be included in this review paper. In addition to the abovementioned two databases, Google Scholar was also used to identify more articles on active sportswear fabric properties and their effect on fabric drying and moisture management. When selecting papers to review, priority was given to those that had recently been published (2018 to the present) and were relevant to this study. A total of 37 articles were reviewed from the two selected databases and Google Scholar, which were published from 2018 to 2023.

2.2. Characteristics of Active Sportswear Fabric

Textile materials are used for active sportswear in all kinds of sports [35,47]. The performance of an active sportswear fabric is critical to athletes. The use of innovative textile science and technology in the manufacturing of sportswear fabrics is continuously being improved [47]. Some of the desirable attributes of functional active sportswear include heat transfer, air permeability, moisture absorption, durability, light weight, and smooth texture [21,22]. The designers must consider factors like protection and safety, comfort, flexibility, and aesthetics when designing active sportswear [48,49]. To meet these factors, fabrics that are breathable, quick drying, thermally stable, and stretchy have been developed [47]. Functional active sportswear needs to transfer moisture effectively to maintain the standard body temperature [47]. Active sportswear also needs to be designed in such a way so that it can provide protection against UV rays to the athletes [29,48,49].

It is an exceedingly difficult task to design active sportswear universally as the required conditions differ depending on the target group and environmental conditions. For instance, some sports may require the best-possible physical performance, short wear time, and fixed weather. In contrast, other sports may not concern themselves with physical performance but instead require long-term wear time with varying weather conditions [50]. Regardless of the type of activity, clothing comfortability has become the most demanding feature for athletes [29,49]. Research on active sportswear fabrics has been progressing to maintain maximum comfort.

Clothing comfort is the single-most important parameter when it comes to active sportswear [27]. Comfort in clothing is a complex system due to the processes involved in heat and mass transfer from the body to the environment through the clothing layers. It is also subjective to humans [4,51]. It depends on many factors, including thermo-physiological, sensorial, and physiological perceptions [52,53]. These factors are directly related to the moisture transmission behavior of clothing [3,54]. The thermo-physiological comfort of active sportswear is maintained by the drying ability of fabrics from water vapor transmission and sweat absorption [55,56]. Fabric comfort is also controlled by its ability to wet and wick moisture vapor [10,12]. When it comes to active sportswear, fabrics that transfer the sweat away from the skin are highly desirable for the wearer's comfort [14]. Proper moisture transfer is essential to keep the body temperature controlled for the wearers during exercise [57]. Researchers have found that the most important factors of a fabric to maintain clothing comfortability are drying and moisture management properties [58]. Table 1 shows a summary of the effect of comfortability of active sportswear.

Table 1. Characteristics of active sportswear fabric.

Findings		Source
Comfortability	Comfort is key in active sportswear. Clothing comfort is complex and mostly depends on thermo-physiological, sensory, and physiological perceptions.	[4,27,52,53]
Active sportswear attributes	Heat transfer, air permeability, moisture absorption, durability, light weight, and smooth texture are some of the common attributes of functional active sportswear. The ability of a fabric to adsorb water and dry quickly is one of the most important factors to maintain comfortability during any physical activity.	[10,12,21,22]

2.3. Fabric Drying Performance

The rate at which a fabric dries has a big effect on how warm and comfortable the wearer feels. It mostly depends on the properties, structure, and finishing of the fabric [59]. Consumers usually wear active sportswear during any sports activity or workout, which makes them sweat a lot [25]. When sweat is present, there is more friction between the fabric and the skin. This causes a clingy feeling and, over time, makes the wearer feel more tired. This problem increases when people take part in sports-related activities or exercise. Fabric with good drying properties can minimize the wet sensation by removing the sweat from the skin [60]. As soon as the wearer starts to sweat, the clothing adsorbs the sweat and makes the wearer's skin dry quickly [61]. The sweat spreads over the surface of the fabric and evaporates to cool the body [62]. In contrast, clothing with poor drying performance causes low sweat evaporation, resulting in a failure to cool down the body effectively. The fabric drying mechanism comprises the three steps listed here [62]:

1. Sweat absorption from the wearer's skin
2. Transmission of sweat to the fabric's outer side
3. Evaporation of sweat into the atmosphere

The fabric drying mechanism is directly related to the moisture management capacity of the fabric. Moisture transfer in fabric occurs when water vapor and liquid water move from the skin of the wearer to the atmosphere through the fabric [11]. Moisture management of the fabric is the most important phenomenon in cases where physical exertion causes a high rate of sweating [11]. It controls the thermo-physiological comfort level of the fabric regardless of the type of fibers by keeping it dry [60]. Additionally, the thermal insulation of clothing reduces significantly with the accumulation of sweat within the clothing [63]. Proper moisture transfer improves the athlete's performance by providing maximum comfort and better physiological conditions [57,64,65]. Moisture management has become the key performance criterion in today's active sportswear industry. This mechanism involves absorbing sweat from the skin, transporting the sweat to the outer surface of the fabric, and finally releasing the humidity into the surrounding air [44]. The breathability of a fabric depends on the rate of water vapor permeability through the fabric materials [66]. Water vapor is transmitted through the fabric from the skin to the outer surface by using the diffusion technique. The wicking characteristic of the fabric determines how fast it can transfer the absorbed sweat to the outer surface [11]. Moisture management of active sportswear depends on the environmental conditions [67] and is critical for athletes where exhaustive physical activities occur [13–15]. If sweat is not absorbed and evaporated in hot weather, the body will not feel cool [67]. On the contrary, in cold weather, when sweat occurs without absorption, it will make the person feel colder [67]. Proper moisture transfer through fabric improves the fabric's drying performance, which maintains the body temperature at a favorable level. Additionally, when the moisture takes time to dry from the skin and remains on the surface of the skin, there is an increase in skin friction [68]. This increases the perception of roughness and wetness, which, in turn, makes the clothing less comfortable to be worn in hot environments [69]. Table 2 shows the effect of moisture management on active sportswear performance.

Table 2. Effects of moisture transmission on active sportswear.

Findings		Source
Moisture transmission process	The fabric transfers water vapor and liquid from the skin. Wicking determines how quickly the fabric removes sweat. Moisture transfer of a fabric also depends on the moisture amount and environmental conditions.	[11,44,70]
Significance	Moisture management in active sportswear is critical for athletes, and it is needed in both cold and hot weather. Proper moisture transfer improves athlete performance by maximizing comfort and physiological conditions.	[14,15,57,65,67]

Based on the research that has been conducted, it is clear that the ability of active sportswear fabrics to dry quickly is one of the most important factors for the wearer's physical comfort. However, active sportswear fabrics have not been extensively investigated to determine how sweat-drying performance changes depending on fiber types and ambient factors. Also, not much research has been conducted to find out the relationship between an active sportswear fabric's ability to manage moisture and how quickly it dries.

2.4. Impact of Fabric Properties on Drying Performance

2.4.1. Fiber Type

Fabrics are woven or knitted from fibers, which serve as the fabric's building blocks. Some of the common natural fibers include cotton, wool, and silk, while man-made/manufactured fibers (regenerated or synthetic) include rayon, polyester, nylon, and acrylic. Fabric properties, such as strength, durability, drape, and texture, are determined by the type of fiber used [71]. A number of fiber-based fabrics are currently used for active sportswear apparel, including natural, synthetic, and blends of two or more fibers [28,29]. The ability of a certain fabric to transfer moisture depends on its moisture content and environmental conditions [70]. It is critical for a wearer to select a suitable fabric based on their physical demands as well as environmental conditions. Synthetic active sportswear performs effectively at maintaining the body temperature during exercise due to its high-wicking property [33,34]. The wicking property of a fabric assists in transferring liquid sweat from the wearer's skin to the outer surface of the clothing through the yarns and evaporating it from the outer surface by the capillary force [11]. Polyester is the most popular fiber when it comes to moisture management in fabrics [25,35]. Researchers have found that moisture management is significantly higher in polyester cloth compared to cotton cloth [72,73]. Some of the main aspects of polyester fiber are low density, chemical inertness, soft hand feel, machine washability, wrinkle and abrasion resistance, better tensile strength, and low cost in the textile industry [47]. Polyester fibers are naturally hydrophobic, similar to polypropylene, nylon, and acrylic fibers, and adsorb less moisture compared to cotton fibers [12,35,73,74]. However, advanced technology has been applied to increase the moisture management performance of polyester fiber [28,75,76]. Gorade et al. investigated the performance and quick-drying properties of modified polyester fabric by adding microcrystalline cellulose [76]. Like polyester, spandex fiber is also commonly used in sportswear due to its stretchiness and flexibility. Spandex does not provide moisture management by itself, but when combined with other fibers or used in certain fabrics, it improves their moisture management performance [35]. Knitted fabric with micro-denier polyester showed better moisture transmission compared to spun polyester [77,78]. Additionally, nanofiber and conductive technologies have been applied to develop new types of fabric to improve moisture transfer properties [5,79].

Cellulosic fibers, including cotton and viscose, are hydrophilic in nature. These fibers absorb moisture easily from the skin [17]. However, this high absorbency makes liquid transportation difficult [74,80]. Ha et al. found that cotton clothing provides higher comfort than polyester at a certain sweat rate [36]. Wool fiber has also higher moisture regain than all other fibers at a certain temperature and relative humidity [81,82], but it gives a wet sensation on the skin when the fabric absorbs moisture [82]. Adler and Walsh studied moisture transport to examine the moisture transfer through fabrics at low moisture contents [70]. Interestingly, they found that wicking between the fabric does not take place at a low level of moisture content [70]. Das et al. also studied the moisture flow mechanism of blended fabrics [66]. Interestingly, they found that although hygroscopic fabric has higher absorbency of water vapor, it shows low liquid moisture transmission behavior as it cannot transport water between capillaries [66]. Öner et al. studied the liquid absorption and transmission of knitted fabrics made of cotton, viscose, and polyester yarns separately [17]. They found that loose-fitting fabrics are able to transfer liquid at a higher rate compared to close-fitting fabrics regardless of the type of material [17]. Table 3 summarizes the use of different types of fibers in active sportswear.

Table 3. Fibers used in active sportswear.

	Findings	Source
Natural	Cellulosic fibers, for example, cotton and wool, absorb moisture better than other fibers. This high absorbency of cotton makes liquid transportation difficult. The drying performance of natural fibers depends on factors like the sweat rate, ambient temperature, and relative humidity.	[17,80,82]
Synthetic	The high-wicking property of synthetic or blended synthetic active sportswear makes it more effective at keeping the body warm while working out. Despite polyester fibers being hydrophobic and adsorbing less moisture compared to natural fibers, they are the most widely used fibers for moisture control in fabrics.	[12,23,33,34]

Existing research shows different types of fibers act differently in transferring moisture to maintain clothing comfort. Little research has been conducted on the evaluation of different types of fibers based on the sweat volume. To the best of our knowledge, few studies have considered both the environmental impact and the wearer's sweat volume to evaluate the performance of different types of fabrics.

2.4.2. Fabric Structure

Fabric structure has a significant impact on moisture transport [30–32]. Implementing smart yarn and manufacturing technologies improves the quality of knitted fabrics [83]. Knitted fabrics have become popular in active sportswear due to their stretchability, wrinkle resistance, and ability to fit close to the body, which are important for the freedom of movement in sports-related activities [28,38–41]. Researchers have found that the advancement in knitting technology has a significant impact on the moisture management of fabrics [84]. Kim and Kim (2007) investigated the physical attributes associated with intelligent coolness features, such as the comfort of wear, exhibited by knitted fabrics made from Huvis elastic fiber (HEF) [85]. To achieve the intended objective, three distinct types of covered filament yarn samples, namely PET-HEF, Aerocool-HEF, and PET-spandex, were fabricated. Subsequently, knitted fabric samples were produced using these covered yarn specimens. Due to HEF's good moisture affinity and the high open space created by its self-extension, HEF-PET-covered yarns and their knitted fabrics had better moisture absorption and drying properties than spandex-PET knitted fabrics [85]. Yang et al. investigated the drying performance of knitted fabrics [86]. They found that both knitting structure and yarn composition significantly impact the drying performance. They also found that fabric with a large mesh structure has better drying performance compared to fabric with a plain structure [86]. Another study conducted by the same researchers found that fabric structure and finishing patterns significantly impact moisture management properties [87]. For their study, the authors used four different finishing patterns based on the ratio of hydrophilic area to hydrophobic area. The higher this ratio, the more regularity in the pattern, which results in better performance in unidirectional water transmission and thermal-wet comfortability [87]. Parada et al. conducted an investigation to study wicking in woven and simple jersey knit [88]. The fabric samples were composed of yarns made from four different materials, namely cotton, polyethylene terephthalate, polyamide, and polypropylene. The study revealed that wicking characteristics are primarily influenced by the fiber composition rather than fabric parameters, such as the yarn twisting level, fabric structure, or wicking direction [88].

Active sportswear clothes are usually made of two-sided fabrics [89,90]. Usually, a hydrophobic fiber is used as the inner layer and a hydrophilic layer is used as the outer layer [89]. The placement of hydrophilic layers close to the skin is typically associated with a higher degree of moisture absorption compared to hydrophobic layers [91]. The chemical composition of the hydrophilic layer includes polar molecules that attract water molecules.

When a hydrophilic fabric comes into contact with moisture, the moisture is drawn into the fabric and distributed, increasing the surface area for evaporation and allowing the fabric to dry faster. Several researchers have used a moisture management tester (MMT) to study moisture transfer performance in knitted active sportswear fabrics. Suganthi and Senthilkumar (2018) studied seven bilayer knitted active sportswear fabrics to compare moisture management performance by using a moisture management tester (MMT) [27]. For the study, they used different yarn combinations, including viscose–polypropylene, modal–polypropylene, viscose–microfiber polyester, modal–microfiber polyester, viscose–polyester, modal–polyester, and bamboo–polyester, for the outer and inner layers. It was found that microfiber polyester as the inner layer and modal as the outer layer had the best moisture management properties among the tested samples. Their study demonstrated that a better wetting time, a high wetting radius, a good absorption rate, and a good spreading speed of sweat can provide a high level of comfort when it comes to active sportswear [27]. The same researchers looked into the impact of tri-layer knitted structures on the thermal comfort properties of layered knitted fabrics in another study [92]. Three tri-layer knitted structures with microfiber polyester inner layers and modal outer layers were created. Microfiber polyester, polyester, or acrylic yarns were used for the middle layer. From this experiment, they found that a tri-layer knitted structure with microfiber polyester in the inner and middle layers and modal in the outer layer provides better thermal comfort than polyester or acrylic in the middle layer [92]. Another study used different proportions of cotton/polylactic-acid-fiber-blended knitted fabrics to evaluate dynamic moisture transport properties using the SDL Atlas MMT. Overall, it was found that the cotton/polylactic acid fiber 65:35 blended fabric is better at managing moisture than the 100% cotton fabric [93]. Manshahia and Das (2014) used an MMT to study plated knitted active sportswear [25]. It was found that when high-shape-factor filaments are combined, the fabric has better moisture management with a larger wetting radius, higher one-way transport capacity, and a quick absorption rate. The effect is stronger when the fabric is next to the skin [25]. Troynikov (2011) used an MMT to conduct research to find out how knitted fabrics made of different ratios of wool/polyester and wool/bamboo blends handle liquid moisture and how well they work as the base layer of active sportswear [90]. Different parameters, for example, wetting time, absorption rate, wetted radius, spreading speed, one-way transport of moisture, and overall moisture management capacity, were measured for each fabric sample and compared. When compared to the non-blended fabric, 100% bamboo had the fastest wetting time on both the top and the bottom. When compared to the blended fabrics, wool/bamboo blends had a higher wetting time than wool/polyester blends. When wool is mixed with polyester or bamboo, the fabrics are better at managing moisture than when they are made of 100% wool or 100% bamboo [90].

Along with the fiber composition, researchers have found that the effects of yarn structure and weaving structure significantly impact the moisture management properties of the fabrics [94]. The structure of a yarn has significant effects on its ability to manage moisture. Due to the increased surface area, open yarns, such as looped or textured ones, absorb and transport moisture more efficiently. Due to their dense structure, closed yarns, like staple fibers, have lower moisture management capabilities, making it more difficult to absorb and transport moisture away from the body [11]. Ring spinning yarn paths, like straight, left diagonal, and right diagonal, have been studied for their effects on cotton fabric moisture management. The right diagonal yarn path in cotton fabric performs better in moisture management compared to other types of yarn paths [95]. A study was conducted to investigate the effect of weave structure on drying performance in two-layer fabric samples. It was found that matt weave performs better at transferring moisture compared to twill weave [96]. Another study examined how yarn linear density affects moisture management in nine double-layer cotton and polypropylene knitted fabrics. The coarser polypropylene inner layer and finer cotton outer layer had higher longitudinal wicking than other specimens. Water absorption time increased with the increase in polypropylene yarn fineness. The double-layer fabric with coarser polypropylene and finer cotton yarn absorbed more water [97].

Fabric performance also varies based on the thickness and weight of the materials. Several studies have found that the physiological responses and performance of athletes are influenced by the weight and thickness of the active sportswear fabrics [4,98]. Another study found that fabric's comfortability is significantly affected by changes in fabric thickness [25]. The drying performance of a fabric also depends on the thickness of the fabric [99,100]. Thicker and heavier fabrics show poor drying performance compared to thinner and lighter fabrics [59]. Also, fabrics with a higher thickness and weight usually have lower moisture transfer ability [17]. A study was conducted by Prakash and Ramakrishnan to find out the effect of fabric thickness on moisture management properties [101]. They found that the wicking ability of a fabric depends on the thickness of that fabric [101]. Table 4 shows the effects of fabric structure on the drying performance of active sportswear.

Table 4. Effects of fabric structure on active sportswear.

	Findings	Source
Knitted fabrics	Blended knitted fabrics show better performance in fabric drying compared to pure natural or synthetic fabrics. Bilayer knitted fabrics improve moisture transmission by creating a capillary action that helps move moisture away from the skin and distribute it throughout the fabric.	[12,27,90,93]
Thickness and weight	The athletes' physiological responses and performance are affected by the weight and thickness of the active sportswear fabrics. Variations in fabric thickness have a substantial impact on the level of comfort provided by the fabric. The drying performance of thicker and heavier fabrics is weaker compared to that of thinner and lighter fabrics.	[4,25,59,98,101]

2.4.3. Air Permeability

Air permeability is an important parameter to consider for affecting the drying performance, because it helps transmit air through the fabric. Air transfer between the clothing and the outside environment controls the thermal insulation and water vapor resistance characteristics of a fabric [102]. When air is transmitted through the fabric, there is a greater chance that the fabric will dry faster. That is why air permeability can be an important parameter. Moreover, during physical activity, the athlete's body releases heat and sweat. Sweat is absorbed by the fabric, which gets wet. In this state of wetness, the fabric's air permeability must be sufficient for effective vapor transfer. If the fabric's air permeability is insufficient, sweat will condense on the skin, eventually reducing the fabric's drying performance [103].

A research study revealed that the air permeability of a fabric is influenced by various factors, such as fiber type, yarn, rigidity, weight, and other fabric properties [104,105]. Another study investigated how fabric properties affect air permeability and concluded that a fabric's air permeability decreases as the percentage of cotton in the fabric increases [106]. Likewise, another study reached similar conclusions, stating that 100% cotton fabric has lower air permeability compared to blended cotton and other fiber fabrics. This is primarily due to the higher presence of hairiness on the surface of cotton fibers, which obstructs the fabric's porosity. As a result, airflow through the fabric is reduced, leading to decreased air permeability [107].

Ahmad et al. found that since micro-denier polyester fabric is so dense, it allows less air to pass through than traditional polyester and cotton fabric [108]. They found that air permeability decreases as the number of filaments in a yarn with a certain linear density increases [108]. Moreover, Badr et al. investigated the air permeability of different types of fabric produced from different types of fibers [109]. The findings suggest that single jersey fabrics made of 100% modal, 100% micro-modal, and 100% bamboo have higher air permeability compared to other fabrics made from cotton or cotton blends. Indeed, cotton is made up of "convolutions," which are long, ribbon-like bundles. As the cotton fiber matures, the lumen dries out and collapses, causing the secondary wall to twist. This twist in the fibers and the extra-hairy fibers of cotton yarns make cotton samples less breathable than modal fibers [109].

Other studies have investigated the relationship between fabric characteristics and air permeability. Salopek et al. reported that single-knit fabric allows more air to pass through than double-knit fabric [110]. Many investigations have shown that fabric thickness inversely affects material air permeability. Single-knit fabric allows greater airflow since it is thinner than double-knit fabric. Because of its denser structure, double-knit fabric has lower air permeability than single-knit fabric [42,111].

A study investigated whether the loop length and fabric gauge are also important for air permeability [112]. Loop length is defined as the length of each loop or stitch in a knitted fabric, and the mass per unit area refers to the weight of fabric per unit area [113]. Fabric that is constructed with a longer loop length tends to have a lower number of loops within a specific area, causing a lower amount of material within the fabric and consequently reducing the mass per unit area. Conversely, fabric constructed with a shorter loop length tends to have a higher number of loops within the same area, causing a higher amount of material within the fabric and consequently increasing the mass per unit area [114]. In relation to air permeability, a knit fabric with longer loop lengths will generally have higher air permeability. The larger gaps between the loops allow more air to pass through the fabric, increasing its breathability [115]. This can be expected in certain applications where ventilation of clothing or moisture management of fabric is vital, such as sportswear or lightweight summer garments [116,117]. Conversely, knit fabrics with shorter loop lengths tend to have a compact structure with smaller gaps between the loops. This results in lower air permeability, as less air can pass through the structure [115].

Fabric gauge and breathability have an opposite relationship because a higher fabric gauge results in a more compact structure, which eventually reduces airflow through the fabric [105]. Some other researchers have found that the type of knit loop is equally important as the fabric gauge and the loop length. They have reported that the percentage of tuck stitches in the structure of a single-knit fabric is directly proportional to its air permeability. As a result of their increased porosity, air can easily pass through loose knitted structures made with tuck stitches as opposed to those made with knit or miss stitches. There is more airflow and ventilation in a tuck-stitched structure than in a knit-stitched one [118,119].

Researchers have found that not only fabric parameters but also yarn parameters, such as the yarn count, twist, and yarn structural properties, contribute to the air permeability of a fabric. The yarn count, which represents the thickness of the yarn, affects air permeability by influencing the packing density of the fabric. Finer yarns result in a more open fabric structure, increasing the passage of air [120]. The twist factor of a yarn plays a significant role in determining the air permeability of fabrics. The majority of fabrics demonstrate higher air permeability with an increase in the yarn twist factor. Twist refers to the number of spiral turns given to a yarn to secure its constituent fibers or threads together. This twisting process is essential for providing yarns with coherence and strength. When a yarn is subjected to greater twist, it becomes more tightly compacted, resulting in increased spaces within the yarn structure. Consequently, this enhances the air permeability of the fabric [121]. However, yarn structural parameters, including the diameter, irregularity, crimp, and surface texture, also play a role. Irregularities and variations in diameter promote a more open structure [122]. It is important to consider these factors alongside fabric construction, fiber type, and finishing treatments for a comprehensive understanding of air permeability in textiles.

Researchers have also investigated the impact of mechanical factors on air permeability. Some of the studies have concluded that stretching has an effect on air permeability. In its stretched state, a fabric's permeability is greater than in its relaxed state. As a result of fabric stretching, porosity increases, allowing more air to pass through [123,124]. Table 5 shows the effects of air permeability on fabric drying.

Table 5. Effects of air permeability on active sportswear.

	Findings	Source
Fabric structure	• The knitted construction affects air permeability. Single-knit cloth is more permeable to air than double-knit fabric.	[110]
	• The length of the loop impacts air permeability by altering the fabric's tightness and air volume. Shorter loops provide a denser, more compact fabric, but longer loops permit more airflow.	[105]
	• Fabrics with a high gauge are less air-permeable and less breathable than those with a low gauge. • The air permeability of a yarn decreases as the number of filaments increases.	[108]
Fiber type	• The hairiness of cotton is usually slightly higher than that of man-made fibers, which block porosity and reduce air permeability.	[106,107]
	• Micro-denier polyester fabric has poorer air permeability than conventional polyester and cotton due to its tight weave.	[108]

In the existing body of research, there is a lack of holistic investigation regarding how air permeability can affect the drying performance of fabric due to changes in fiber, yarn, fabric properties, and fabric structures. The dry rate performance of fabric can change due to changes in fiber, yarn, fabric parameters, and air permeability. This could be a thorough study in the field of thermo-physiological comfort in active sportswear.

2.4.4. Surface Texture

Drying performance also depends on how quickly water is absorbed, transported through the fabric, and exposed to ambient air. The quicker the transportation of water through the fabric, the quicker the drying time. However, moisture transport might be correlated with fabric surface texture. The texture of clothing plays a significant role in skin comfort, health, and the occurrence of friction-related skin problems. Various factors, including fiber composition, yarn construction, fabric structure, and surface finishes, influence the frictional properties of clothing. Fabrics made from yarns with higher frictional properties tend to have higher friction. The frictional behavior of fibers is affected by factors such as the fiber cross-sectional shape, molecular orientation, and fiber type. Yarn friction, in contrast, is influenced by yarn composition, spinning systems, and yarn topography [125].

When it comes to wetting phenomena, particularly in fibrous materials, the curvature and roughness of contact surfaces play a crucial role. These materials have complex, convoluted, and flexible rough structures [126]. The roughness and energy of a solid surface affect its wettability. The Wenzel model and the Cassie–Baxter model are commonly used to describe the relationship between surface roughness, energy, and contact angle. The Wenzel equation measures the contact angle on a rough surface, which increases with surface roughness for hydrophobic surfaces and decreases it for hydrophilic surfaces [127].

The Wenzel model is applied when the surface roughness is less than or equal to 1.7 times the static contact angle [128]. Beyond this threshold, the contact angle hysteresis decreases, indicating the transition to the Cassie–Baxter regime. In the Cassie–Baxter regime, water droplets are suspended on the surface, creating a composite phase with an increased air fraction. The contact angle in this regime increases irrespective of surface energy. The Cassie–Baxter model assumes a solid surface composed of solid and air pockets forming a composite interface. It suggests that if the liquid partially wets the surface and air is trapped within the roughness features, the droplet exhibits a composite contact angle. The droplet rests on the tops of surface asperities, with only some portions in direct contact with the solid. Trapped air pockets reduce the overall contact area and limit wetting behavior [128]. However, both Wenzel and Cassie–Baxter models are static and do not account for dynamic effects, like droplet spreading and retraction, evaporation, and droplet motion. They provide a snapshot view of wetting behavior at a specific moment and do not consider the progressive evolution of wetting phenomena. In terms of water absorption and friction, a smooth surface has a larger contact area with water molecules, resulting in increased friction and water absorption. Conversely, a rough surface minimizes the contact area between the fabric and water molecules, reducing friction and repelling water. This concept is used in self-cleaning mechanisms by creating surface roughness and applying various types of nano-coatings to fabrics. The self-cleaning property often referred to as the lotus effect compares to the characteristics of lotus leaves. Lotus leaves have small bumps called papillae, which are smaller and have pointed tops compared to the surrounding cells. These papillae reduce the contact area with water droplets, preventing water from sticking to the leaves [129]. Fabrics with a rough surface have a higher water absorption rate, allowing them to quickly absorb sweat from the inner layer and transfer it to the outer layer, facilitating rapid evaporation. However, fabrics with a smooth surface repel water, absorbing sweat at a slower rate and delaying its transfer from the inner to the outer layer, resulting in slower drying [127].

The association between fabric surface texture and its implications for drying efficacy remains inadequately explored, prompting the need for an in-depth investigation into how fabric surface texture influences the drying performance of active sportswear fabrics. Undertaking such research would not only bridge existing knowledge gaps but also contribute valuable insights into the field of fabric performance analysis. Table 6 shows the effects of surface texture on fabric drying.

Table 6. Effects of surface texture on active sportswear.

	Findings	Source
Structure	A smooth surface is composed of equally distributed fibers with little interstices between them. A smooth surface increases the contact area between cloth and water, while a rough surface decreases the contact area.	[127]
Drying performance	A smooth surface soaks moisture quickly compared to a rough surface, and therefore, the dry rate property of textiles might be different depending on the surface texture.	[129]

2.5. Fabric Drying and Human Physiology

The human body is a complex system that always tries to maintain equilibrium with the environment while performing physical activities [130]. The normal temperature of the human body is 37 °C [11,17]. During any physical exercise, the body temperature rises due to a higher metabolism rate [16]. As the body temperature increases during exercise, skin blood flow increases in order to increase the transfer of metabolic heat from the body's core to the skin [131]. The metabolic heat is also increased by the additional weight of the clothing [132]. To maintain the equilibrium temperature, heat needs to be transferred away from the body [133]. This transfer of heat includes two processes, dry flux and latent flux [12,27,90]. Fabric properties can be classified into two categories, insulation properties and moisture transport properties. The former control dry flux, and the latter control latent flux. It is essential to pass body vapor and liquid sweat away from the skin to the environment effectively [13,64,65,134]. If moisture transfer occurs properly, the fabric will start to dry quickly. These dry conditions of the fabric actually provide better thermal comfort to the wearers by transferring their sweat to the ambient environment [19,20]. In a cold environment, the human body exchanges less heat, which results in lower blood circulation in the hands and legs [135]. When a person goes to a warm environment, blood circulation increases to exchange the heat. Sweating occurs to release the surplus latent heat from the body [135] and makes the wearer more easily exhausted [11]. Understanding this phenomenon is critical for athletes to keep them energetic during sporting activities.

The evaporation of sweat from the skin's surface is the major mechanism for cooling the human body during sports activity [130]. During periods of rest, approximately 25% of the total heat loss can be attributed to evaporative heat exchange. However, when exposed to hot environments and/or during exercise, it becomes the primary means of heat loss [136]. It has been shown that 1 g of water evaporated at the body temperature takes away 0.578 kcal [137]. Another study found that evaporation of sweat from the skin accounts for ~55% of heat loss during physical exertion and is thus the primary means of cooling during exercise [138]. One of the most important barriers to evaporative heat loss during exercise is the insulating layer generated by clothing on the outside of the body [139]. During exercise, the body goes through a series of physiological changes that affect the cardiovascular, respiratory, and thermoregulatory systems, as well as other parts of the body. The removal of heat generated by muscle action is a critical issue during exercise in both warm and cold weather conditions. The use of clothes, in general, serves as an additional layer of insulation, thereby preventing heat transfer [140] and evaporation from the skin surface [137]. Table 7 illustrates how the human body maintains equilibrium when its temperature rises and it begins to sweat.

Table 7. Effects of human physiology on active sportswear.

	Findings	Source
Body temperature	The human body is a complex system that always tries to maintain equilibrium with the environment while performing physical activities. During any physical activities, the body temperature rises due to a higher metabolism rate.	[16,90]
Ambient conditions	Sweat evaporation is the major mechanism for cooling the body during sports activity, and clothing prevents heat loss. In a cold environment, the human body exchanges less heat, which results in lower blood circulation. In contrast, in a warm environment, blood circulation increases to exchange heat.	[135,139]

Human physiology is the most critical factor when it comes to active sportswear fabric. Existing research shows different types of active sportswear fabrics impact the level of tiredness during sports-related activities. Heat generation increases during any sports-related activity due to a higher metabolic rate. It is important to dissipate this heat from the body to maintain comfort. More research is needed to see how active sportswear fabrics can effectively lower the wearer's body temperature and maintain equilibrium.

2.6. Environmental Effects on Fabric Drying

Clothing is the human–environment interface. Apart from the cultural meaning, clothing protects against cold, sun, wind, rain, and other environmental hazards (chemicals, mechanical). Thermoregulation is first affected by textile materials. These insulate and resist sweat. These provide both thermal insulation and resistance to sweat vapor transfer [132]. The point of sweating is to get the water on the wearer's skin to evaporate and cool down. There are four things in the environment that affect how much the wearer sweats: temperature, humidity, sun exposure, and wind. The first three factors have a similar effect on sweating. The more or higher these factors are available in the environment, the more the wearer sweats. The last factor, wind, can change frequently, which makes it difficult to predict the effect of wind on sweating [141]. Relative humidity is a way of measuring how humid the air is. It is a ratio between the quantity of water in an air sample and the highest amount of water the air can contain at a given temperature [142]. When humidity rises, hygroscopic fibers, such as wool and cotton, absorb moisture vapor from the surrounding air and release heat. Similarly, when the humidity drops, moisture is released and fibers absorb heat [51]. A study showed that when humidity goes up, sweat evaporation becomes slower [143]. Another study found that low relative humidity speeds up the drying process, while higher relative humidity reduces the drying rate [144]. At a high level of humidity, the air has a high concentration of water molecules. Under these circumstances, the scattered water molecules may condense with the water molecules in the surrounding air and cling to the fabric. This phenomenon actually slows down the drying process [145]. If the humidity of the air passing over the fabric is lower than the humidity of the dispersing air on the fabric's surface, the evaporation process is accelerated [26]. The effect of air temperature on sweat drying has also been studied by several researchers. Temperature affects the rate of evaporation to a lesser extent than relative humidity. However, these two factors are interconnected. As air temperature rises, it can adsorb more liquid, causing relative humidity to fall [144]. The drying time of sweat is greatly reduced as the air temperature increases [143]. It is important to note that moisture concentration controls sweat evaporation, not relative humidity. Under ambient conditions with 100% relative humidity, air has different amounts of moisture, depending on temperature. At equal relative humidities, the temperature increases the moisture content. Even at 100% relative humidity, sweat will evaporate when the air temperature is lower than the skin temperature [132].

Researchers have found that the evaporation rate of a fabric is significantly influenced by environmental airflow and that this factor is even more significant than the fabric's properties [59,146]. A study conducted by Mandal et al. found that the drying performance of a fabric increases with increased airflow [26]. Table 8 shows how the drying performance of active sportswear is impacted by environmental factors.

Table 8. Effects of environmental factors on active sportswear.

Findings		Source
Temperature and humidity	The relative humidity and air temperature have an impact on sweat evaporation. With lowering the relative humidity, the air temperature increases sweat absorption.	[143,144]
Airflow	Ambient airflow affects fabric evaporation more than fabric properties, and the rate of sweat drying increases with the airflow.	[26,59]

Previous studies have shown that the drying performance of a fabric depends not only on the fabric's properties but also on the surrounding conditions of the environment. Environmental factors, for example, temperature, humidity, and airflow, impact the moisture transfer from the wearer's skin to the environment. Only a limited amount of research has used these factors to analyze a fabric's drying performance. More research needs to be conducted to identify how the drying performance of different types of active sportswear fabric changes with changes in environmental conditions.

3. Gap in the Existing Literature

Statistical models have been used to analyze data and make predictions in research. Statistical models allow researchers to measure the relationships between different variables and to identify trends and patterns. ANOVA is frequently used by researchers to identify the relationship between the fabric properties and drying performance of fabric samples [59,67,87,147]. Researchers have used statistical modeling techniques, for example, an artificial neural network, to predict a fabric's thermal resistance [148,149]. Another study also used theoretical models to explain heat transfer through the fabric system [150]. However, little research has used these statistical or theoretical models to study the drying performance of active sportswear fabrics and how different fabric properties impact the dry rate. Statistical and/or theoretical models on fabric drying help researchers as well as industry people improve the fabric's drying performance by understanding the effect of different fabric properties. These also help to identify the patterns and relationships between different types of active sportswear fabrics.

Another research gap in fabric drying performance is the change in moisture management properties in response to changes in environmental factors, such as airflow, temperature, and humidity. Current studies related to a fabric's drying mostly consider the effect of breathability and wicking properties. Fabric design that considers fabric properties and environmental factors to improve drying performance and keeping the fabric–skin friction low could improve athletes' comfort and performance. Also, future research could lead to the creation of new materials and ways to better control the amount of moisture in fabrics, which would make them more comfortable and help them perform better.

There is a lack of research in the area of fabric drying performance and the ways in which it can be improved to provide better comfort for a wide range of sweating levels. Further research is needed in order to understand how various fabric properties, including fiber type, fabric structure, air permeability, and surface texture, can affect the sweat drying performance and moisture management of active sportswear fabrics. Additionally, further exploration is needed to assess how fabric drying performance influences comfortability in high-perspiration scenarios. These research gaps are especially important due to the normal physiological response of sweating and the desire for the wearer to remain comfortable and dry.

4. Summary and Conclusions

This article summarized and synthesized the current state of research on the drying performance of active sportswear fabrics. It also highlights the importance of moisture management in textile fabrics, as it can affect the comfort, functionality, and durability of the fabrics. The paper covered previous studies that have investigated the impact of fabric properties, including fiber type, fabric structure, air permeability, and surface texture, on a fabric's drying performance. The review also covered the effects of fabric drying on human physiology and how environmental factors affect the drying performance of active sportswear fabrics. Lastly, the authors identified the gaps in existing research on fabric drying and how future research can improve the quality of active sportswear clothing by providing comfort to the wearer.

Fabric drying performance and moisture management are two important aspects of active sportswear clothing because they help to keep the wearer dry and comfortable during sports-related activities. The literature reviewed in this paper has highlighted the different fabric properties and their significance. The effectiveness of these properties in managing moisture transmission through clothing has been well established; however, there are also limitations and drawbacks in existing research. The review shows a need for more research in certain areas, such as investigating the effect of sweat volume and environmental factors on drying performance. Also, more research needs to be conducted to figure out the relationships between different fabric properties and how statistical modeling can be used to predict how well active sportswear fabrics dry.

The literature reviewed in this article has offered a complete overview of the existing knowledge about fabric drying and moisture management, as well as indicated topics for future research and practical application.

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References

1. Bielefeldt Bruun, M.; Langkjær, M.A. *Sportswear: Between Fashion, Innovation and Sustainability*; Taylor & Francis: Abingdon, UK, 2016; Volume 8, pp. 181–188.
2. Sportswear Market Size, Share & COVID-19 Impact Analysis, by Product Type, End-User, Distribution Channel, and Regional Forecast, 2021–2028. Available online: https://www.fortunebusinessinsights.com/sportswear-market-102571 (accessed on 10 April 2023).
3. Song, G. *Improving Comfort in Clothing*; Elsevier: Amsterdam, The Netherlands, 2011.
4. Finnie, M.E. *A Comparative Study of Commercially Available Comfort Fabrics*; Eastern Michigan University: Ypsilanti, MI, USA, 2014.
5. Agarwal, R.; Jassal, M.; Agrawal, A.K. Nano surface modification of poly (ethylene terephthalate) fabrics for enhanced comfort properties for activewear. *J. Ind. Eng. Chem.* **2021**, *98*, 217–230. [CrossRef]
6. Yetisen, A.K.; Qu, H.; Manbachi, A.; Butt, H.; Dokmeci, M.R.; Hinestroza, J.P.; Skorobogatiy, M.; Khademhosseini, A.; Yun, S.H. Nanotechnology in textiles. *ACS Nano* **2016**, *10*, 3042–3068. [CrossRef] [PubMed]
7. *Cambridge Dictionary*; Cambridge University Press: Cambridge, England, 2023.
8. *Sportswear (Fashion)*; Wikipedia: USA. 2023. Available online: https://en.wikipedia.org/wiki/Sportswear_(fashion) (accessed on 24 March 2023).
9. Bubonia, J.E. *Apparel Production Terms and Processes: Studio Instant Access*, 2nd ed.; Bloomsbury Publishing: New York, UK, USA, 2017.
10. Benltoufa, S.; Fayala, F.; BenNasrallah, S. Capillary rise in macro and micro pores of jersey knitting structure. *J. Eng. Fibers Fabr.* **2008**, *3*, 155892500800300305. [CrossRef]
11. Chinta, S.; Gujar, P.D. Significance of moisture management for high performance textile fabrics. *Int. J. Innov. Res. Sci. Eng. Technol.* **2013**, *2*, 814–819.
12. Sathish Babu, B.; Senthil Kumar, P.; Senthil Kumar, M. Effect of yarn type on moisture transfer characteristics of double-face knitted fabrics for active sportswear. *J. Ind. Text.* **2020**, *49*, 1078–1099. [CrossRef]
13. Fan, J.; Tsang, H.W. Effect of clothing thermal properties on the thermal comfort sensation during active sports. *Text. Res. J.* **2008**, *78*, 111–118.
14. Das, A.; Alagirusamy, R.; Kumar, P. Study of heat transfer through multilayer clothing assemblies: A theoretical prediction. *AUTEX Res. J.* **2011**, *11*, 54–60.
15. Kwon, S.-o.; Kim, J.; Moon, M.-W.; Park, C.H. Nanostructured superhydrophobic lyocell fabrics with asymmetric moisture absorbency: Moisture managing properties. *Text. Res. J.* **2017**, *87*, 807–815. [CrossRef]
16. Shirreffs, S.M.; Aragon-Vargas, L.F.; Chamorro, M.; Maughan, R.J.; Serratosa, L.; Zachwieja, J.J. The sweating response of elite professional soccer players to training in the heat. *Int. J. Sports Med.* **2005**, *26*, 90–95. [CrossRef]
17. Öner, E.; Atasağun, H.; Okur, A.; Beden, A.; Durur, G. Evaluation of moisture management properties on knitted fabrics. *J. Text. Inst.* **2013**, *104*, 699–707. [CrossRef]
18. Guyton, A.C. *Basic Human Physiology*; W.B. Saunders Company: Philadelphia, PA, USA, 1977; pp. 615–618.
19. Lin, X.; Li, Y.; Zhou, J.; Cao, X.; Hu, J.; Guo, Y.; Sun, S.; Lv, R.; Lin, Y.; Ye, Q.; et al. Effects of fabrics with dynamic moisture transfer properties on skin temperature in females during exercise and recovery. *Text. Res. J.* **2015**, *85*, 2030–2039. [CrossRef]
20. Onofrei, E.; Codau, T.-C.; Stojanka, P.; Gauthier, B.; Dupont, D.; Damien, S. Analysis of moisture evaporation from underwear designed for fire-fighters. *AUTEX Res. J.* **2015**, *15*, 35–47.
21. Mayer, W.; Mohr, U.; Schuierer, M. High-Tech-Textilien der Beitrag der Ausrüstung am Beispiel der funktionellen Sport-und Freizeitbekleidung. *Int. Text. Bull. Veredl. 2. Quart.* **1989**.
22. Haberstock, H. Special polyester yarn knitted fabric for sportswear with optimum functional and physiological properties. *Milliand Int.* **1990**, *6*, E125–E127.
23. Manshahia, M.; Das, A. High active sportswear–A critical review. *Indian J. Fibre Text. Res. (IJFTR)* **2014**, *39*, 441–449.

24. Pakdel, E.; Naebe, M.; Sun, L.; Wang, X. Advanced functional fibrous materials for enhanced thermoregulating performance. *ACS Appl. Mater. Interfaces* **2019**, *11*, 13039–13057. [CrossRef] [PubMed]
25. Manshahia, M.; Das, A. Moisture management of high active sportswear. *Fibers Polym.* **2014**, *15*, 1221–1229. [CrossRef]
26. Mandal, S.; Chowdhury, I.Z.; Mazumder, N.-U.-S.; Agnew, R.J.; Boorady, L.M. Characterization of Sweat Drying Performance of Single Layered Thermal Protective Fabrics Used in High-Risk Sector Workers' Clothing. *Polymers* **2022**, *14*, 5393. [CrossRef] [PubMed]
27. Suganthi, T.; Senthilkumar, P. Moisture-management properties of bi-layer knitted fabrics for sportswear. *J. Ind. Text.* **2018**, *47*, 1447–1463. [CrossRef]
28. Higgins, S.; Anand, M. Textiles materials and products for activewear and sportswear. *Tech. Text. Mark.* **2003**, *52*, 9–40.
29. Venkatraman, P. Fabric properties and their characteristics. *Mater. Technol. Sportsw. Perform. Appar.* **2015**, 53–86.
30. Emirhanova, N.; Kavusturan, Y. Effects of knit structure on the dimensional and physical properties of winter outerwear knitted fabrics. *Fibres Text. East. Eur.* **2008**, *16*, 67.
31. McGregor, B.; Postle, R. Mechanical properties of cashmere single jersey knitted fabrics blended with high and low crimp superfine Merino wool. *Text. Res. J.* **2008**, *78*, 399–411. [CrossRef]
32. Gorea, A.; Baytar, F.; Sanders, E. Effect of stitch patterns on moisture responsiveness of seamless knitted wool fabrics for activewear. *Int. J. Cloth. Sci. Technol.* **2020**, *33*, 175–187. [CrossRef]
33. Roberts, B.C.; Waller, T.M.; Caine, M.P. Thermoregulatory response to base layer garments during treadmill exercise. *Int. J. Sports Sci. Eng.* **2007**, *1*, 29–38.
34. Manshahia, M.; Das, A. Comfort characteristics of knitted active sportswear: Liquid water transportation. *Res. J. Text. Appar.* **2013**, *17*, 38–49. [CrossRef]
35. Shishoo, R. *Textiles for Sportswear*; Elsevier: Amsterdam, The Netherlands, 2015.
36. Ha, M.; Tokura, H.; Yanai, Y.; Moriyama, T.; Tsuchiya, N. Combined effects of fabric air permeability and moisture absorption on clothing microclimate and subjective sensation during intermittent exercise at 27 degrees C. *Ergonomics* **1999**, *42*, 964–979. [CrossRef]
37. Heinisch, T.; Bajzík, V.; Hes, L. New methodology and instrument for determination of the isothermal drying rate of cotton and polypropylene fabrics at constant air velocity. *J. Eng. Fibers Fabr.* **2019**, *14*, 1558925019873482. [CrossRef]
38. Stegmaier, T.; Mavely, J.; Schneider, P. High-performance and high-functional fibres and textiles. In *Textiles in Sport*; Elsevier: Amsterdam, The Netherlands, 2005; pp. 89–119.
39. Vincent, J.F. The materials revolution. *J. Bionic Eng.* **2006**, *3*, 217–234. [CrossRef]
40. Anbumani, N.; Babu, B.S. Comfort properties of bi-layer knitted fabrics. *Indian Text. J.* **2008**, *4*, 17–28.
41. Tiwari, S.K.; Fei, P.T.C.; McLaren, J.D. A pilot study: Evaluating the influence of knitting patterns and densities on fabric properties for sports applications. *Procedia Eng.* **2013**, *60*, 373–377. [CrossRef]
42. Oğulata, R.T.; Mavruz, S. Investigation of porosity and air permeability values of plain knitted fabrics. *Fib. Tex. East. Eur.* **2010**, *18*, 71–75.
43. Berglund, L.G.; Gonzalez, R.R. Evaporation of sweat from sedentary man in humid environments. *J. Appl. Physiol.* **1977**, *42*, 767–772. [CrossRef] [PubMed]
44. Kissa, E. Wetting and wicking. *Text. Res. J.* **1996**, *66*, 660–668. [CrossRef]
45. Dougherty, E. Why Do We Sweat More in High Humidity? Available online: https://engineering.mit.edu/engage/ask-an-engineer/why-do-we-sweat-more-in-high-humidity/ (accessed on 10 September 2022).
46. Palmatier, R.W.; Houston, M.B.; Hulland, J. *Review Articles: Purpose, Process, and Structure*; Springer: Berlin/Heidelberg, Germany, 2018; Volume 46, pp. 1–5.
47. Uttam, D. Active sportswear fabrics. *Int. J. IT Eng. Appl. Sci. Res.* **2013**, *2*, 34–40.
48. Chaudhari, S.S.; Chitnis, R.S.; Ramkrishnan, R. Waterproof breathable active sports wear fabrics. *Man-Made Text. India* **2004**, *5*, 166–171.
49. Özdil, N.; Anand, S. Recent Developments in Textile Materials and Products Used for Activewear and Sportswear. *Electron. J. Veh. Technol./Tasit Teknol. Elektron. Derg.* **2014**, *8*, 68–83.
50. Umbach, K. Aspects of clothing physiology in the development of sportswear. *Knitt. Tech.* **1993**, *15*, 165–169.
51. Li, Y. The science of clothing comfort. *Text. Prog.* **2001**, *31*, 1–135. [CrossRef]
52. Bivainytė, A.; Mikučionienė, D. Investigation on the air and water vapour permeability of double-layered weft knitted fabrics. *PES* **2011**, *8*, 29.
53. Onofrei, E.; Rocha, A.M.; Catarino, A. The influence of knitted fabrics' structure on the thermal and moisture management properties. *J. Eng. Fibers Fabr.* **2011**, *6*, 155892501100600403. [CrossRef]
54. Tang, K.-p.M.; Kan, C.-w.; Fan, J.-t. Assessing and predicting the subjective wetness sensation of textiles: Subjective and objective evaluation. *Text. Res. J.* **2015**, *85*, 838–849. [CrossRef]
55. Demiryürek, O.; Uysaltürk, D. Thermal comfort properties of Viloft/cotton and Viloft/polyester blended knitted fabrics. *Text. Res. J.* **2013**, *83*, 1740–1753. [CrossRef]
56. Senthilkumar, P. Comfort characteristics of cotton hollow yarn knitted fabrics: Part 3—Structural properties. *Man-Made Text. India* **2018**, *46*, 163–167.
57. Fratzl, P.; Weinkamer, R. Nature's hierarchical materials. *Prog. Mater. Sci.* **2007**, *52*, 1263–1334. [CrossRef]

58. Wang, Z.; Li, Y.; Kowk, Y.; Yeung, C. Mathematical simulation of the perception of fabric thermal and moisture sensations. *Text. Res. J.* **2002**, *72*, 327–334. [CrossRef]
59. Chau, K.-H.; Tang, K.-P.M.; Kan, C.-W. Constant temperature drying rate tester: Real-time water evaporation measurement of fabrics. *IEEE Trans. Instrum. Meas.* **2018**, *67*, 2635–2648. [CrossRef]
60. Tang, K.-P.M.; Kan, C.-W.; Fan, J.-t. Evaluation of water absorption and transport property of fabrics. *Text. Prog.* **2014**, *46*, 1–132. [CrossRef]
61. Filingeri, D.; Fournet, D.; Hodder, S.; Havenith, G. Mild evaporative cooling applied to the torso provides thermoregulatory benefits during running in the heat. *Scand. J. Med. Sci. Sports* **2015**, *25*, 200–210. [CrossRef]
62. Arens, E.A.; Zhang, H. *The Skin's Role in Human Thermoregulation and Comfort*; Woodhead Publishing Ltd.: Cambridge, UK, 2006.
63. Chen, Y.; Fan, J.; Zhang, W. Clothing thermal insulation during sweating. *Text. Res. J.* **2003**, *73*, 152–157. [CrossRef]
64. Zhuang, Q.; Harlock, S.; Brook, D. Transfer wicking mechanisms of knitted fabrics used as undergarments for outdoor activities. *Text. Res. J.* **2002**, *72*, 727–734. [CrossRef]
65. Kothari, V.; Sanyal, P. Fibres and fabrics for active sportswear. *Asian Text. J.-Bombay* **2003**, *12*, 55–61.
66. Das, B.; Das, A.; Kothari, V.; Fanguiero, R.; Araujo, M.D. Moisture flow through blended fabrics–Effect of hydrophilicity. *J. Eng. Fibers Fabr.* **2009**, *4*, 155892500900400405. [CrossRef]
67. Özkan, E.T.; Meric, B. Thermophysiological comfort properties of different knitted fabrics used in cycling clothes. *Text. Res. J.* **2015**, *85*, 62–70. [CrossRef]
68. Kenins, P. Influence of fiber type and moisture on measured fabric-to-skin friction. *Text. Res. J.* **1994**, *64*, 722–728. [CrossRef]
69. Gwosdow, A.; Stevens, J.; Berglund, L.; Stolwijk, J. Skin friction and fabric sensations in neutral and warm environments. *Text. Res. J.* **1986**, *56*, 574–580. [CrossRef]
70. Adler, M.M.; Walsh, W.K. Mechanisms of transient moisture transport between fabrics. *Text. Res. J.* **1984**, *54*, 334–343. [CrossRef]
71. Sinclair, R. Understanding textile fibres and their properties: What is a textile fibre? In *Textiles and Fashion*; Elsevier: Amsterdam, The Netherlands, 2015; pp. 3–27.
72. Tokura, H. The effect of moisture and water absorbency of fibers on the sweating rates of sedentary man in hot ambient environmants. *Object. Specif. Fabr. Qual. Mech. Prop. Perform.* **1982**, *1982*, 407–417.
73. Dong, Y.; Kong, J.; Phua, S.L.; Zhao, C.; Thomas, N.L.; Lu, X. Tailoring surface hydrophilicity of porous electrospun nanofibers to enhance capillary and push–pull effects for moisture wicking. *ACS Appl. Mater. Interfaces* **2014**, *6*, 14087–14095. [CrossRef] [PubMed]
74. Behra, B.; Mani, M.; Mondal Amit, K. Comfort behaviour of cotton polypropylene based bi-layered knitted fabrics. *Asian Text. J.* **2002**, *41*, 61–67.
75. Wang, F.; Zhou, X.; Wang, S. Development processes and property measurements of moisture absorption and quick dry fabrics. *Fibres Text. East. Eur.* **2009**, *17*, 46–49.
76. Gorade, V.G.; Chaudhary, B.U.; Kale, R.D. Polyester fabric with moisture management properties using a sol–gel technique for activewear. *J. Polym. Res.* **2021**, *28*, 1–13. [CrossRef]
77. Srinivasan, J.; Ramakrishnan, G.; Mukhopadhyay, S.; Manoharan, S. A study of knitted fabrics from polyester microdenier fibres. *J. Text. Inst.* **2007**, *98*, 31–35. [CrossRef]
78. Sampath, M.; Mani, S.; Nalankilli, G. Effect of filament fineness on comfort characteristics of moisture management finished polyester knitted fabrics. *J. Ind. Text.* **2011**, *41*, 160–173. [CrossRef]
79. Scott, J. Responsive Knit: The evolution of a programmable material system. In Proceedings of the DRS2018, Design Research Society, Limerick, Ireland, 25–28 June 2018; pp. 1800–1811.
80. Kyatuheire, S.; Wei, L.; Mwasiagi, J.I. Investigation of moisture transportation properties of knitted fabrics made from viscose vortex spun yarns. *J. Eng. Fibers Fabr.* **2014**, *9*, 155892501400900318. [CrossRef]
81. Baird, K. Relaxation shrinkage of wool fabrics: Its release with regain and time. *Text. Res. J.* **1961**, *31*, 624–629. [CrossRef]
82. Gioello, D. *Understanding Fabrics: From Fiber to Finished Cloth*, 1st ed.; Fairchild: New York, NY, USA, 1982.
83. McCann, J. The garment design process for smart clothing: From fibre selection through to product launch. In *Smart Clothes and Wearable Technology*; Elsevier: Amsterdam, The Netherlands, 2009; pp. 70–94.
84. Öner, E.; Okur, A. The effect of different knitted fabrics' structures on the moisture transport properties. *J. Text. Inst.* **2013**, *104*, 1164–1177. [CrossRef]
85. Kim, H.A.; Kim, S.J. Moisture responded transformable property of intelligent coolness knitted fabrics for sportswear clothings. *Autex Res. J.* **2017**, *17*, 250–258. [CrossRef]
86. Yang, Y.; Yu, X.; Chen, L.; Zhang, P. Effect of knitting structure and yarn composition on thermal comfort properties of bi-layer knitted fabrics. *Text. Res. J.* **2021**, *91*, 3–17. [CrossRef]
87. Yang, Y.; Chen, L.; Naveed, T.; Zhang, P.; Farooq, A. Influence of fabric structure and finishing pattern on the thermal and moisture management properties of unidirectional water transport knitted polyester fabrics. *Text. Res. J.* **2019**, *89*, 1983–1996. [CrossRef]
88. Parada, M.; Vontobel, P.; Rossi, R.M.; Derome, D.; Carmeliet, J. Dynamic wicking process in textiles. *Transp. Porous Media* **2017**, *119*, 611–632. [CrossRef]
89. Patnaik, A.; Rengasamy, R.; Kothari, V.; Ghosh, A. Wetting and wicking in fibrous materials. *Text. Prog.* **2006**, *38*, 1–105. [CrossRef]
90. Troynikov, O.; Wardiningsih, W. Moisture management properties of wool/polyester and wool/bamboo knitted fabrics for the sportswear base layer. *Text. Res. J.* **2011**, *81*, 621–631. [CrossRef]

91. Rossi, R.M.; Gross, R.; May, H. Water vapor transfer and condensation effects in multilayer textile combinations. *Text. Res. J.* **2004**, *74*, 1–6. [CrossRef]
92. Suganthi, T.; Senthilkumar, P. Development of tri-layer knitted fabrics for shuttle badminton players. *J. Ind. Text.* **2018**, *48*, 738–760. [CrossRef]
93. Guruprasad, R.; Vivekanandan, M.; Arputharaj, A.; Saxena, S.; Chattopadhyay, S. Development of cotton-rich/polylactic acid fiber blend knitted fabrics for sports textiles. *J. Ind. Text.* **2015**, *45*, 405–415. [CrossRef]
94. Gungor Turkmen, B.; Celik, P.; Sehit, H.; Bedez Ute, T. The effects of hollow yarn and fabric structure on permeability and moisture management properties of woven fabrics. *J. Text. Inst.* **2023**, 1–8. [CrossRef]
95. Jebastin Rajwin, A.; Prakash, C. Effect of modified yarn path on ring spinning on the moisture management properties of the cotton fabrics. *J. Nat. Fibers* **2021**, *18*, 1332–1343. [CrossRef]
96. Niles, N.; Fernando, S.; Rathnayake, N.; Hewamalavi, A.; Weerasinghe, S. Two-layer fabrics for moisture management. *Res. J. Text. Appar.* **2021**, *25*, 64–74. [CrossRef]
97. Babu, B.S.; Senthilkumar, P.; Senthilkumar, M. Effect of yarn linear density on moisture management characteristics of cotton/polypropylene double layer knitted fabrics. *Ind. Textila* **2015**, *66*, 123.
98. Hassan, M.; Qashqary, K.; Hassan, H.A.; Shady, E.; Alansary, M. Influence of sportswear fabric properties on the health and performance of athletes. *Fibres Text. East. Eur.* **2012**, *4*, 82–88.
99. Prahsarn, C.; Barker, R.L.; Gupta, B. Moisture vapor transport behavior of polyester knit fabrics. *Text. Res. J.* **2005**, *75*, 346–351. [CrossRef]
100. Au, K.-F. *Advances in Knitting Technology*; Elsevier: Amsterdam, The Netherlands, 2011.
101. Prakash, C.; Ramakrishnan, G. An effect of fabrics thickness and structure on moisture management properties of 3D spacer fabrics. *Int. J. Cloth. Sci. Technol.* **2019**, *31*, 777–789.
102. Bouskill, L.; Havenith, G.; Kuklane, K.; Parsons, K.; Withey, W. Relationship between clothing ventilation and thermal insulation. *AIHA J.* **2002**, *63*, 262–268. [CrossRef]
103. Nayak, R.; Kanesalingam, S.; Houshyar, S.; Wang, L.; Padhye, R.; Vijayan, A. Evaluation of thermal, moisture management and sensorial comfort properties of superabsorbent polyacrylate fabrics for the next-to-skin layer in firefighters' protective clothing. *Text. Res. J.* **2018**, *88*, 1077–1088. [CrossRef]
104. Li, J.; Zhang, Z.; Wang, Y. The relationship between air gap sizes and clothing heat transfer performance. *J. Text. Inst.* **2013**, *104*, 1327–1336. [CrossRef]
105. Suganthi, T.; Senthilkumar, P.; Dipika, V. Thermal comfort properties of a bi-layer knitted fabric structure for volleyball sportswear. *Fibres Text. East. Eur.* **2017**, *25*, 75–80. [CrossRef]
106. Kotb, N.; Salman, A.; Ghazy, H.; Abu El-Anain, E. Quality of summer knitted fabrics produced from microfiber/cotton yarns. *J. Basic Appl. Sci. Res.* **2011**, *1*, 3416–3423.
107. Babu, K.M.; Chandrasekhara, S.M. Chapter six—Production and properties of bamboo yarns and fabrics. In *Bamboo Fibres*; Babu, K.M., Chandrasekhara, S.M., Eds.; Woodhead Publishing: Cambridge, UK, 2023; pp. 137–168.
108. Ahmad, H.S.; Jamshaid, H. Development of thermo-physiologically comfortable knit structure for sports application. *Text. Appar.* **2019**, *29*, 105–112. [CrossRef]
109. Badr, A.A.; Hassanin, A.; Moursey, M. Influence of Tencel/cotton blends on knitted fabric performance. *Alex. Eng. J.* **2016**, *55*, 2439–2447. [CrossRef]
110. Salopek Čubrić, I.; Potočić Matković, V.M.; Pavlović, Ž.; Pavko Čuden, A. Material and Structural Functionalization of Knitted Fabrics for Sportswear. *Materials* **2022**, *15*, 3306. [CrossRef] [PubMed]
111. Tugrul Ogulata, R.; Mavruz Mezarcioz, S. Optimization of air permeability of knitted fabrics with the Taguchi approach. *J. Text. Inst.* **2011**, *102*, 395–404. [CrossRef]
112. Prakash, C.; Ramakrishnan, G.; Mani, K.; Keerthana, S. An investigation of the relationship between blend ratio, linear density and loop length on geometrical and air permeability properties of bamboo cotton-knitted fabrics. *Int. J. Fash. Des. Technol. Educ.* **2015**, *8*, 228–234. [CrossRef]
113. Shobanasree, P.; Prakash, C.; Kumar, M.R.; Lokesh, K. Effect of Elastane Plating on Physical & Thermal Comfort Properties of Lyocell Single Jersey Knit Fabric with Different Loop Length. *J. Nat. Fibers* **2022**, *19*, 11574–11581.
114. Das, S.; Hossain, M.; Rony, M.S.H.; Hashan, M.M.; Haque, A.U.; Majumder, M. Analyzing Technical Relationships among GSM, Count and Stitch Length of (1×1) Rib and (1×1) Grey Interlock Fabric. *Int. J. Text. Sci.* **2017**, *6*, 64–71.
115. Munden, D. 26—The geometry and dimensional properties of plain-knit fabrics. *J. Text. Inst. Trans.* **1959**, *50*, T448–T471. [CrossRef]
116. Kanakaraj, P.; Ramachandran, R. Active Knit Fabrics-Functional Needs of Sportswear Application. *J. Text. Appar. Technol. Manag. (JTATM)* **2015**, *9*. Available online: https://ojs.cnr.ncsu.edu/index.php/JTATM/article/view/6785/3585 (accessed on 24 March 2023).
117. Teyeme, Y.; Malengier, B.; Tesfaye, T.; Vasile, S.; Van Langenhove, L. Comparative analysis of thermophysiological comfort-related properties of elastic knitted fabrics for cycling sportswear. *Materials* **2020**, *13*, 4024. [CrossRef]
118. Kumar, V.; Sampath, V.; Prakash, C. Investigation of stretch on air permeability of knitted fabrics part II: Effect of fabric structure. *J. Text. Inst.* **2016**, *107*, 1213–1222. [CrossRef]
119. Selli, F.; Turhan, Y. Investigation of air permeability and moisture management properties of the commercial single jersey and rib knitted fabrics. *Text. Appar.* **2017**, *27*, 27–31.

120. Bhattacharya, S.; Ajmeri, J. Air permeability of knitted fabrics made from regenerated cellulosic fibres. *Int. J. Eng. Res. Dev.* **2014**, *10*, 16–22.
121. Tastan, E.; Akgun, M.; Gurarda, A.; Omeroglu, S. Investigation of the effect of different structural parameters of cotton woven fabrics on their air permeability. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *254*, 182014. [CrossRef]
122. Havlová, M. Detection of fabric structure irregularities using air permeability measurements. *J. Eng. Fibers Fabr.* **2014**, *9*, 155892501400900419. [CrossRef]
123. Mohammadi, M.; Banks-Lee, P.; Ghadimi, P. Air permeability of multilayer needle punched nonwoven fabrics: Experimental method. *J. Ind. Text.* **2002**, *32*, 139–150. [CrossRef]
124. Atalie, D.; Tesinova, P.; Tadesse, M.G.; Ferede, E.; Dulgheriu, I.; Loghin, E. Thermo-physiological comfort properties of sportswear with different combination of inner and outer layers. *Materials* **2021**, *14*, 6863. [CrossRef] [PubMed]
125. Baby, R.; Mathur, K.; DenHartog, E. Skin-textiles friction: Importance and prospects in skin comfort and in healthcare in prevention of skin injuries. *J. Text. Inst.* **2021**, *112*, 1514–1530. [CrossRef]
126. Pan, N.; Gibson, P. *Thermal and Moisture Transport in Fibrous Materials*; Woodhead Publishing: Cambridge, UK, 2006.
127. Shirtcliffe, N.; Comanns, P.; Hamlett, C.; Roach, P.; Atherton, S. The Effect of Roughness Geometry on Superhydrophobicity and Related Phenomena. *Mater. Sci. Mater. Eng.* **2019**, 291–308. [CrossRef]
128. Boulange-Petermann, L.; Joud, J.; Baroux, B.; Mittal, K. *Contact Angle, Wettability and Adhesion*; CRS Press: Boca Raton, FL, USA, 2008.
129. Ensikat, H.J.; Ditsche-Kuru, P.; Neinhuis, C.; Barthlott, W. Superhydrophobicity in perfection: The outstanding properties of the lotus leaf. *Beilstein J. Nanotechnol.* **2011**, *2*, 152–161. [CrossRef]
130. Kenny, G.; Flouris, A. The human thermoregulatory system and its response to thermal stress. In *Protective Clothing*; Elsevier: Amsterdam, The Netherlands, 2014; pp. 319–365.
131. Ferguson, J. *Does Clothing Made of Synthetic Versus Natural Fabrics Enhance 20-km Cycling Time Trial Performance in Endurance-Trained Athletes?* McGill University: Montreal, QC, Canada, 2017.
132. Havenith, G. Interaction of clothing and thermoregulation. *Exog. Dermatol.* **2002**, *1*, 221–230. [CrossRef]
133. Kenny, G.P.; Jay, O. Thermometry, calorimetry, and mean body temperature during heat stress. *Compr. Physiol.* **2011**, *3*, 1689–1719.
134. Wang, F.; Annaheim, S.; Morrissey, M.; Rossi, R. Real evaporative cooling efficiency of one-layer tight-fitting sportswear in a hot environment. *Scand. J. Med. Sci. Sports* **2014**, *24*, e129–e139. [CrossRef] [PubMed]
135. Hu, J.; Li, Y.; Yeung, K.-w.; Wong, A.S.; Xu, W. Moisture management tester: A method to characterize fabric liquid moisture management properties. *Text. Res. J.* **2005**, *75*, 57–62. [CrossRef]
136. Gagnon, D.; Jay, O.; Kenny, G.P. The evaporative requirement for heat balance determines whole-body sweat rate during exercise under conditions permitting full evaporation. *J. Physiol.* **2013**, *591*, 2925–2935. [CrossRef]
137. Gavin, T.P. Clothing and thermoregulation during exercise. *Sports Med.* **2003**, *33*, 941–947. [CrossRef] [PubMed]
138. Plowman, S.A.; Smith, D.L. *Exercise Physiology for Health Fitness and Performance*; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2013.
139. Wilmore, J.H.; Costill, D.L.; Kenney, W.L. *Physiology of Sport and Exercise*; Human Kinetics: Champaign, IL, USA, 2004; Volume 20.
140. Wang, F. Modelling of cold stress and cold strain in protective clothing. In *Protective Clothing*; Elsevier: Amsterdam, The Netherlands, 2014; pp. 366–391.
141. Schubert, L. Hydration: Environmental Factors that Influence Sweat Rate. Available online: https://nutritionheartbeat.com/sports-nutrition/hydration-environment-sweat-rate (accessed on 16 January 2023).
142. Wang, Y.; Qiao, Q.; Cao, J.; Zhi, C.; Li, C.; Tao, Y. Characterizing the effects of controlled temperature and relative humidity on liquid water transport behavior of cotton/lycra elastic woven fabric. *Mater. Res. Express* **2021**, *8*, 055301. [CrossRef]
143. Cay, A.; Gurlek, G.; Oglakcioglu, N. Analysis and modeling of drying behavior of knitted textile materials. *Dry. Technol.* **2017**, *35*, 509–521. [CrossRef]
144. Gluesenkamp, K.R.; Patel, V.K.; Momen, A.M. Efficiency limits of evaporative fabric drying methods. *Dry. Technol.* **2021**, *39*, 104–124. [CrossRef]
145. Das, A.; Alagirusamy, R. Neurophysiological processes in clothing comfort. *Sci. Cloth. Comf.* **2010**, 31–53.
146. Chen, Q.; Fan, J.; Sun, C. The comfort evaluation of weft knitted plant structured fabrics and garment. II. Sweating manikin and wearer trial test on polo shirt. *Fibers Polym.* **2015**, *16*, 2077–2085. [CrossRef]
147. Suganthi, T.; Senthilkumar, P. Thermal comfort characteristics of bi-layer knitted fabrics for sportswear. *Int. J. Fash. Des. Technol. Educ.* **2018**, *11*, 210–222. [CrossRef]
148. Mandal, S.; Song, G. An empirical analysis of thermal protective performance of fabrics used in protective clothing. *Ann. Occup. Hyg.* **2014**, *58*, 1065–1077. [PubMed]
149. Kanat, Z.E.; Özdil, N. Application of artificial neural network (ANN) for the prediction of thermal resistance of knitted fabrics at different moisture content. *J. Text. Inst.* **2018**, *109*, 1247–1253. [CrossRef]
150. Mandal, S.; Song, G. Characterizing thermal protective fabrics of firefighters' clothing in hot surface contact. *J. Ind. Text.* **2018**, *47*, 622–639. [CrossRef]