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Review of functional and protective clothing for sports

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Abstract
Worldwide, a wide range of functional clothing and equipment are being developed to suit various sports, to support and enhance the player's performance. Many innovative technologies are integrated into sports clothing to make the player reach peak performance. Most sports injuries are occurring annually due to collisions and contact. A lot of research is focused on developing clothing to prevent and protect players from minor to major, life-threatening sports injuries. This paper attempts to review the existing and developing areas of functional and protective clothing and equipment for sports.

Keywords: Functional clothing, layering system, comfort mapping, smart clothing, sports protective clothing, traumatic brain injury

Introduction
Functional clothing refers to various types of clothing or assemblies which are specifically manufactured to provide functionality to the wearer, other than normal functions. Sports functional clothing is a category of functional clothing, which helps in enhancing the performance of sportsmen. Sports clothing, which differs from casual clothing and has improved functionality to meet the specific requirement is known as functional sports clothing [1].

Functional sports clothing
Functional clothing is classified into many categories, based on specific functionality [1]. In addition to this specific functionality, all categories of functional clothing should meet certain common requirements, such as physical, physiological, ergonomic and psychological requirements.

Physiological requirements: The physiological requirements depend on human anatomy and physiology. The design of the garment, materials used, size, fit, and the response of the garments to cold and warm climates will decide the success of the functional clothing in meeting physiological requirements. Thermal regulation, energy metabolism and ambient climatic conditions affect physiological requirements. Factors such as evaporation of moisture, penetration of thermal radiation, moisture interaction with clothing, and ventilation of clothing also affect physiological requirements [2].

Biochemical requirements: the Biochemical requirements encompass kinematic, mechanical, dynamic, and behavioral aspects of physical activities such as crawling, climbing, firefighting, crouching, flood relief, etc. As interactions take place between different parts of the human body and clothing, the fit and shape of the garment, pressure, and friction exerted by the garment on body parts, affect biomechanical requirements. Sometimes, pressure may be applied on certain body parts for therapeutic purposes also. Muscles can bear the pressure better than bones. In the case of sportswear, pressure may be exerted in the form of compression, on selective muscles to improve the player's performance and decrease fatigue. Body sculpting clothing also works on the principle of compression, lifts, or supports certain body parts, depending on the biomechanical requirement. However, while designing sports clothing care should be taken, so that there should not be too little compression, which will render it ineffective and not too much compression, which may cause swelling [2, 3].

Ergonomic requirements: "Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system and the profession that applies theory, principles, data and methods to design in order to optimize

human well-being and overall system performance" [4]. According to ergonomics, the body movement and motion, extent of freedom, and movement of joints should match with mechanical properties of clothing. The layout of the workplace and regulations of health and safety must be considered while designing functional clothing. A garment that does not have a proper fit can obstruct movements and compromise the safety and performance of the player [2].

Psychological requirements: Humans react, feel, think and act differently in different circumstances. Clothing is a way of expressing personality and strong feelings influence the selection of clothing and preference for aesthetics. Sports clothing that is very comfortable and provides great functionality may be rejected by players sometimes if they are not convinced that it is reflecting their personal image and they don't consider it as smart clothing. In some sports, such as skiing, tennis, badminton, swimming, motor biking, etc. the aesthetic appeal of the clothing is equally important as functionality. Hence, based on their socio-cultural background, gender, age, location, activity, etc. the functional clothing should be designed to meet the wearer's psychological requirements [2].

Any kind of sports requires increased levels of absorption, breathability, and moisture transfer due to increased metabolism during sports activities. Many outdoor sports may need water or air proofing, protection from wind, UV radiation, drag (high-speed sports), etc., The functionality required for sports clothing is determined by factors such as the type of sport, its environment, the type of clothing construction required and aerodynamics involved, and physiological conditions related to the sports activity. Hence, the designing of functional sports clothing is done based on certain principles, viz. aerodynamic principles to reduce wind drag during high-speed sports, the principle of compression in clothing to provide support and maintain blood flow to certain parts of the body (stockings, socks, bands, leggings, etc.) and elastic body molded suits made with engineering compression gradient. The compression principle is adopted to enhance oxygen supply, remove lactic and facilitate faster recovery from training and exercise [1]. Compression also causes a reduction of oscillatory displacement of muscles, by providing increased neurotransmission at the molecular and cellular levels [5]. The drag caused by resistance to wind can be reduced by modifying the morphology of the material surface or by decreasing the fabric's permeability to air and water or changing the pattern shape and placement of fasteners and seams on sports clothing. It was found that, by decreasing the drag, performance can be increased multifold [1]. The clothing based on aerodynamics (used for high-speed sports such as cycling, sprinting, speed skating, ski jumping, and swimming [1]) encloses a thin layer of air next to the skin of the wearer. Both compression and aerodynamics may be used in combination to improve the functionality of sportswear [6].

Wearable technologies

"Wearable technologies" are the latest development in functional sports clothing, where sensors may be embedded in different layers of the clothing. In intimate clothing such as undergarments, lying next to skin, or base layer, vital sign sensors may be embedded. In the middle layer, thermal regulation and protection, and in the outer layer, electronic user interfaces that are textile-based may be added [7].

Layering system

The latest development in functional clothing for sports is adopting a 'layering system' which was earlier tried and tested in military clothing. This consists of the 'interdependent base layer, a middle insulation layer, and a protective outer layer. The functionality of this clothing is enhanced by selecting a mix of technical textiles and assemblies, using innovative cutting and construction processes (molding, bonding, and laser finishing). Technical textiles may contribute to various functions such as protection, thermal regulation, breathability, stretch ability, walkability and lightweight, physiological and ergonomic requirements of the wearer [8].

In the layer system, the inner layer provides an interface between the body and the textile. It is generally connected with an insulation layer. These two layers can be provided with user interfaces in the form of switches, buttons, and connectors giving input to the garments. The data transfer happens externally between the clothing and the external network [8, 9].

In the case of extreme sports, smart garments are used, which are specifically made for the particular requirement. For example, providing special pockets to accommodate electronic modules, to prevent interference in performing sports. Some sports might require contact with water. Wet clothing can be harmful at low temperatures and during warm conditions perspiration could pose a problem. Hence smart garments are designed to provide thermal regulation. Synthetics such as polypropylene or neoprene are chosen for this purpose. In addition, the design of smart clothing must provide freedom of movement, by adding elastic inserts in the areas where there is maximum adherence to the wearer's body [8, 10].

Construction of sports functional clothing

Comfort mapping: The term comfort mapping indicates, the spatial distribution of moisture and heat produced in different parts of the human body using different textile materials. For example, a breathable, wick able textile under the armpit will keep the part dry, and a windproof textile on the back and chest areas gives protection from cold wind. The principle of comfort mapping is based on the thermoregulation of the human body [11].

When the body is exposed to extremely cold temperatures, in skiing, ice skating, etc. the thermal regulation system of the body automatically starts a protective mechanism, which helps in prevent the core parts of the body viz. brain, torso, and chest from losing heat. Some parts of the body such as feet, hands and skin lose heat fast. Certain cold receptors present in the skin help in sensing extreme cold temperatures. There is more receptor located on the head and torso than extremities. By understanding the way, the body's thermal regulation system works, clothing should be designed to provide maximum comfort and protection. This is known as comfort mapping [11].

In the sportswear sector, the concept of "comfort mapping technology" is widely used. This technology links the physical and physiological requirements of the wearer directly with the 2D and 3D pattern making. The textiles required are procured based on specific fiber properties. The construction method is selected to enhance functionality as well as

comfort. Certain zones of the body in relation to comfort are identified and mapped to incorporate freedom of movement, ergonomic posture, moisture management, environmental and impact protection, and thermal regulation [10].

Smart clothing

Many innovative developments in sportswear resulted in enhanced stimulus-responsive aerogels and polymers, aerodynamics and special coatings for thermal and moisture management [9]. The size of sensors was also reduced, enabling, integration into specialized textiles, to synthesize, "smart clothing". Smart clothing helps players to give the highest of performance, meeting all four types of requirements viz. physiological, biomechanical, ergonomic, and psychological requirements. Smart clothing systems are classified as passive, active and ultra-smart categories. Passive smart clothing can perceive data from 334 muscles, tendons, and ligaments [12].

Smart clothes can sense physiological parameters, such as calorie count, step count, heart rate, etc. Ultra-smart clothing is integrated with microcomputers with diverse data types, to sense, predict and respond to external conditions such as thermoregulation [10].

The designer must be aware of the commercial culture of major events and the specialist press pertinent to the target market, as well as the international trade fairs where leading fiber and fabric producers promote new developments. Trend forecasting with regard to color, styling, and mood may be consulted for fabrics and apparel design direction within certain sectors.

Sports protective clothing

Many athletes and sportspeople worldwide, every year are meeting with injuries that occur during sports [13]. It was found that most of these injuries are caused by not wearing protective gear. A wide range of sports clothing is developed and tested every year. But the acceptance by athletes depends on wear ability, comfort, breathability, weight, and non-hindrance in body movements. Though sports protection clothing is effective in providing protection from impact and shock absorption, most athletes don't prefer to wear them, as they come in the way of freedom of movement and cause discomfort [14]. Sports are classified into three categories based on the type and severity of injuries occurring, Collision/ contact sports, limited-contact sports, and non-contact sports. Sports injuries rarely cause death but injuries caused by collision and adventurous sports can cause fatality. Some of the brain injuries in American children are attributed to sports [15].

Regulations/standard tests for sports protective clothing

The protective equipment for sports impact is tested by following regulations of the American Society for Testing and Materials (ASTM) and the National Operating Committee on Standards for Athletic Equipment (NOCSAE) of the US. NOCSAE has initially begun its regulation with a focus on football helmets and their role in providing protection from injuries. The regulations enforced the reconditioning and recertification of all football helmets every year [13].

Protective materials

The majority of the sport impact materials utilize highly resilient materials [15]. The most commonly used impact materials are foams, gels and textiles. Foams are widely used for impact absorption. They convert the kinetic energy of an impacting object, to other energy forms, less harmful to the body. Foams are categorized as elastic and non-elastic, closed cell and open cell foams. Gels are used to absorb shock. They are commonly used to provide protection to the foot, hand, and joints. These gels can be inserted as pads to treat ankle sprain and pain in other bony areas of the body. They do not provide long-term protection. Air management pads are a recent development in sports impact materials. They provide maximum shock absorption properties with minimum weight. Textiles are also widely used to provide impact protection. Many protective pads and supporting equipment are made with felts. They can be used to prevent swelling in the ankle. The tensile strength resiliency and durability of felts make them suitable for sports protection clothing. Thermoplastic fibers are used as fiber fills in splints and custom pads.

Types of protective clothing for sport impact injuries

Based on the type of sport, the tendency for the occurrence of certain injuries is anticipated. Therefore, many categories of protective clothing are developed for protecting body parts that are more prone to getting impact injuries.

Head protection

As the brain floats freely in cerebrospinal fluid, in case of collision impact, it moves at a different speed than the skull, resulting in a collision between the skull and brain. The high-speed deceleration caused by this impact will cause long axons at the base of the brain to be stretched and diffused leading to axonal injury. Neurological dysfunctions might be caused by such injuries [16, 17, 18, 19, 20].

Traumatic Brain Injury (TBI): At times during sports, TBI may occur. Many athletes with TBI may not undergo treatment as symptoms vary. TBI may cause concussion due to direct or indirect impact on the head, face, neck, and body, resulting in a change of mental status or some of the post-concussion symptoms [16, 21, 22, 23]. It was found that 1.6-3.8 million athletic concussions happen every year [16, 21, 22, 23]. Sometimes concussions may result in memory loss lasting for a few months [16, 20]. Sometimes, post-concussion symptoms may include emotional, cognitive, and physical changes for a long duration [16, 25, 26].

Helmets

The majority of sports involve the probability of head injuries. They are baseball, football, ice hockey, boxing, softball, cricket, white water rafting, cycling, etc. [15]. The most common gear used for head protection includes helmets. Helmets have a great influence on reducing fatalistic head injuries. Helmets are padded headgear used in various sports. They were found to prevent head injuries [27]. Protective helmets are a form of specially-designed medical equipment designed to significantly reduce the risk of head injuries, as well as protect a patient's head following surgery. Safety helmets are usually of three types-Class A, Class B, and Class C. Class A helmets offer users impact and penetration resistance apart from limited voltage protection (up to 2200 volts). It was found that the full-face helmet lowered the risk of facial injury by two-thirds, and confirmed that a full-face helmet offers better protection against facial injury than other types of helmets. HDPE (High-Density Polyethylene) is the

most common plastic used to make hard hats/safety helmets, and versatile with good chemical and impact resistance. PP (Polypropylene) is the second most commonly used plastic in the world and has good chemical and impact resistance also a high melting point. Many types of helmets are developed, each type suitable for a specific sport.

Football helmets: They are made with an outer polycarbonate shell and an inner shell made up of polyethylene, polypropylene, or polyurethane foam with air bladder pads pumped up to fit a specific shape of the head. They must withstand the force equivalent to a player running at 12.2 mph, colliding with a flat surface, and stopping the head at less than 1-inch distance from a collision.
Athletes should follow some guidelines while choosing and wearing football helmets. The wearer must inspect the helmet before wearing it for any deterioration or misplacement in foam padding, cracks, alterations, deflations and malfunction in fasteners. Unless the National Operating Committee on Standards for Athletic Equipment (NOCSAE) certification is given, the helmet should not be worn by athletes [15].
While wearing the helmet, the athlete should dampen hair, and comb the hair, in a way worn during most parts of the season. The fitting of the helmet of the head should be snug, and should not cover the eyes. The ear lines of the helmet should be in line with the ear holes of the wearer and it should cover the skull completely. The helmet should be worn with four snap chin straps to prevent moving of the helmet backward or forward and it should not tilt or shift position when external pressure is applied [15].

Baseball helmets: They are made with an outer shell made of ABS (ACRYLONITIRLE-BUTADIENE-STYRENE) and an inner lining made with EVS (ETHYL VINYL ACETATE) or polypropylene foam. They must absorb impacts of, high velocity, a ball fired at close range to 60 mph.
In recent days many designs of helmets are developed and introduced into minor and major baseball leagues. But their effectiveness in providing protection against concussion is not yet studied. But the role of standard baseball helmets is studied and evaluated [16, 28].

Ice Hockey helmet: Ice hockey is a helmeted sport, like football and involves the risk of concussion. The use of hockey helmets has brought down the incidence of head injuries drastically [16, 29]. They must protect from collision impact, unlike football helmets. Also, must provide protection from low-mass, high-velocity impact forces (like being hit with a stick) in addition to high-mass, low-velocity (like fall). CSA (Canadian Standards Association) provides certification for this category of helmets. The severity of face injury in ice hockey can be reduced by combining helmets with face shields [15].

Bicycling helmets: They are made with an outer shell of ABS, polycarbonate or fiberglass. The inner lining is made with polystyrene, polyurethane, or polyethylene foam. The helmet must absorb a force of "300Gs".

Rugby: Though it was believed that, in rugby orofacial injuries were prevented by the use of mouth guards, it was found in a study made on 304 players of rugby that, there was no remarkable effect of mouth guards on the prevention of concussions [16, 30].

Mouth guards: Mouth guards are used to preventing the incidence of orofacial injuries.

Gum shields: they are worn by players of contact sports such as rugby, lacrosse, and hockey, which involve a collision with hard balls, where the possibility of dental injuries is high [38].

Face protection
Many collisions causing head injuries also cause Orofacial injuries. Protective equipment is developed to prevent irreversible damage to the face and sensory organs. The equipment used for face protection is

Faceguards: They give protection against objects, projectiles, and collisions in sports. Hockey players and football players require protection from injury to the eyes and face [2].

Chin straps: Single straps are used in kayaking and cycling to prevent the movement of the helmet, though allow rotation of the helmet. In the case of football and lacrosse four straps are used to keep the helmet in place and prevent rotation [2].

Eye and ear protection [2]
Collision and contact sports players are prone to eye and ear injuries. Precautions must be taken to prevent these injuries.

Eye protection: in the case of sports like ice hockey, football, baseball, squash, and handball, special precautions must be taken for the protection of the eyes. There are many types of eye protectors developed such as total head protectors (hockey, football, etc.), protectors of full face, specific eye protectors (car racing, ski racing, horse riding, cycling, etc.), partial eye protectors, sports protectors for eyes (baseball, soccer, etc.). Different categories of eye protectors are used to prevent eye injuries. They are

Sports eye protectors: Class I will have a single molded lens and frame, class II will have lenses mounted in a separate frame and class III does not contain lenses, used over eyeglasses.

Goggles: Made with break-proof polycarbonate give good protection during sports [15].

Ear protection: In cases of sports like swimming, boxing, water polo, and wrestling, there is a high possibility of ear injury and players need ear protection. Different types of ear protection devices are used for specific protection. Ear plugs fit inside the ear canal, made from a mold of the person's ear. Ear muffs are external devices that provide ear protection by covering external ears. A helmet is used to cover parts of the head and ears [13].

Upper body protection
Neck protection
Common neck injuries that occur during sports are cervical fractures and cervical dislocation. When one or more of the cervical bones or vertebrae in the neck break, then it is called a cervical fracture. When a ligament injury occurs in the neck, then it is known as cervical dislocation. These injuries can be prevented by wearing protective helmets [40].

Shoulder pads: They are mostly worn by football players. The shoulder pads are of two types. The cantilevered pads are used by goalkeepers and blocking players. They are made with hard plastic material, which protects the chest and back. Players who do not get much impact are given non-cantilevered pads, as they give more freedom of movement and are light in weight. Football pads are used to protect the shoulder, sternum, clavicle, and scapula. The padding extends to cover ribs [15].

Hand protection

The hand is more prone to injuries from sports. In order to exhibit the highest performance in the long term, the player should not get hand injuries [32]. In sports with high player-to-player contact and contact with sports equipment, there is a high risk of hand injuries. The hand is more prone to injury because bones, tendons and ligaments are protected only by a thin layer of fat and skin [33]. Hand juries can range from minor concussions to debilitating bone fractures. Other types of hand injuries include strain, muscle and tendon injury, ligament and joint injuries and joint instability [34]. The part of the hand that is most susceptible to sports injury is the inter phalangeal finger joints. Sometimes, hand injuries may cause chronic pain, stiffness, and deformities also [35].

Gloves: Gloves are part of functional and protective clothing, which covers the whole or part of the hand. Gloves provide protection not only against sports injuries, but provides protection against germs, chemicals, friction, and extreme temperatures (heat and cold) also. In certain sports such as boxing and cricket, gloves play important role in preventing hand injuries. In cricket, batsmen and wicketkeepers wear special gloves. The gloves worn by wicketkeepers will have a barrier layer in between the thumb and forefinger and prevent the ball from slipping from the player's hands [36].

Materials used: Various types of materials are used to make gloves to give maximum protection and to improve performance [37]. They are

Natural Leather: Leather adapts to suit temperature differences and environmental changes. Different types of leather are extracted from different animals. Cow leather is highly durable and withstands extreme temperatures. Pig leather is suitable for dry conditions.

Synthetic Leather: Will appear like natural leather and will have some of the leather's properties. Polyurethane lamination on very thin polyester or polyamide fabric is one type of synthetic leather. This will exhibit good grip, water repellence, and durability. Sometimes, polyurethane fiber is mixed with polyamide to make a non-woven. This is also highly durable and breathable and will have a split leather appearance.

Polyurethane: PU is used as a coating on non-woven and woven textiles. It is a thin pliable material that gives good dry and wet grip and flexibility.

Polyvinylchloride: PVC is highly durable, gives good wet and dry grip and provides protection against harmful chemicals.

Nitrile: This is also known as synthetic rubber. Highly durable and gives good wet and dry grip. Small holes are formed during the manufacturing of the coating. These holes allow the transportation of water vapor, making the gloves very comfortable and flexible. Gives protection from solvents and oils.

Latex: This is natural rubber. Highly elastic, and durable, gives a good wet and dry grip. Highly resistant to chemicals. May cause skin allergies, due to the natural protein present in latex.

Neoprene or chloroprene: Synthetic rubber, gives protection against heat, oil, fat, acids and other chemicals.

Cotton-a natural fiber, highly durable, highly breathable, absorptive, and doesn't melt on exposure to fire. Cotton is used as a lining for welding gloves.

A finger-protective sports glove is developed by the" Exoligamentz" company, to give greater functionality compared to sports tapes, (used to cover fingers and hand to prevent injuries), to reduce repetitive impact, and to support the injured part during recovery [33].

Protection for groin and pelvis in male athletes: Jockstraps are worn by male athletes for groin and pelvis protection. They are suitable for sports, where there is a risk of being hit by a ball below the belt. Jockstraps are similar to regular briefs. However, they will have a pocket for inserting a hard protective plastic cup for protection [39].

Protection of lower limbs [15]

Thigh and hip protection: In the case of contact sports like football and hockey, contusion of the quadriceps (thigh) is a commonly occurring injury. Thigh pads provide protection from these injuries. They should be worn 6-7 inches above the kneecap.

Knee protection: In the case of sports like football and volleyball knee injuries may occur. Knee pads are used to give protection. Knee pads provide protection from blunt trauma by dissipating the impact. Knee braces are also used for this purpose.

Shin protection: In the case of games like ice hockey, baseball and soccer, in order to avoid injury, the players must wear shin guards.

Ankle protection: Many sports which involve running, jumping, and crawling may cause ankle injuries such as twisting, sprain, and fractures. The players need ankle stabilizers for support and ankle braces for preventing sprains.

Conclusion

A wide range of functional clothing and equipment targeting various kinds of sports are developed in recent times. However, the designers and manufacturers must focus on comfort, non-hindrance, ease of care, and durability to suit sports activities, to make the products successful. A lot of research is going on in the field of protective clothing for sports. Many innovative products are developed to impart protection from sports injuries. Sports protection clothing must find the approval of athletes. The researchers and manufacturers should find out the most sustainable production

cycle, with a focus on integrating futuristic technologies.

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