Chapter 7

APPLICATIONS OF COMPRESSION SPORTSWEAR

Praburaj Venkatraman and David Tyler

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1.0 INTRODUCTION

Sport and exercise involves physical movement of the body (torso, upper and lower limbs) and, in some cases, amateurs and professionals alike endure soft tissue injury. At the elite level, improved individual performance during a tournament or a game is vital. Many athletes consider that compression of muscles to support, enhance muscle alignment and improve the efficiency of muscle movements is essential. They also adopt the adage of strapping the injured part to assist recovery from injury. In recent years, there has been an increase in usage and demand for compression garments for a number of sportswear applications and recreational activities due to their ability to offer functional support to the wearer.

The main aim of this chapter is to present research relating to compression garments and highlight the recent developments relating to specific sports such as cycling, skiing and rugby. The benefits of compression garments were documented in various settings (sports, clinical and non-clinical), although convincing evidence remains elusive. The reported benefits of using compression garments were mainly in enhancing blood circulation, reducing the recurrence of injury, aiding recovery, providing muscle support and reducing muscle soreness. However, the claims made by manufacturers in boosting athletes' performance are debatable and the evidence gathered so far is less convincing. The research relating to the benefits and limitations of using compression garments for sportswear is critically reviewed. Most studies used different settings, small sample sizes and it is necessary to question whether the findings should be extrapolated to a wider group. Contextual factors that influence garment design and development such as body shapes, fabric panels, materials properties, sizing and comfort are discussed. In addition, market trends in compression sportswear and factors affecting new product development are discussed in the context of designing innovative compression sportswear.

The main purpose of this chapter is to provide an overview of compression garments available for active sports including, rugby, cycling and skiing. The contents of this chapter will equip the reader to understand the use of compression garments for sportswear, specific application and further their creative thoughts toward developing innovative functional apparel.

2.0 BACKGROUND AND RATIONALE

Compression modalities in the form of elastic compression bandages have been used in the healthcare to control the oedema or swelling of tissues and to aid the return of venous blood from the lower limb to the heart. Several benefits of compression therapy in healthcare have been noted, including: assisting calf muscle to perform its function by restoring damaged valves to function properly, promoting comfort, and quality of life of the patient and enhancing the condition of skin. Compression modalities vary the amount of stretch and elasticity, both intrinsically and extrinsically, in the manner in which they are applied (Figure 1). Recent developments in fibres, fabrics, and finishing technologies enabled researchers to develop compression sportswear that is based on a graded application of pressure to the extremities of the body in order to pump the blood back to the heart faster. Some of the claims of the compression garment developers include improved circulation and performance and reduced recovery times, reduced muscle soreness and enhanced lactic acid removal.

Figure 1: A pair of compression stocking
Source: Shutterstock, Inc.

The rationale of this chapter is to provide an overview of compression garments available for active sports including, rugby, cycling and skiing. It should be noted that compression garments are also widely preferred for aesthetic reasons particularly scar minimisation, reduction of post-surgery infection risk, pain reduction, and slimming support. Compression panties are also used in hernia patients that provide firmness to the tissue and mask any abdominal bulge (Haldane, 2013). It should be noted that whilst compression modalties have demonstrated their effectiveness, the focus of this chapter is on sportswear compression garments.

3.0 COMPRESSION AND ITS INFLUENCE ON PHYSIOLOGY

The principle of compression garments is analogous to compression therapy treatment for lower limbs that involves applying a known amount of pressure to aid the return of venous blood to the heart.

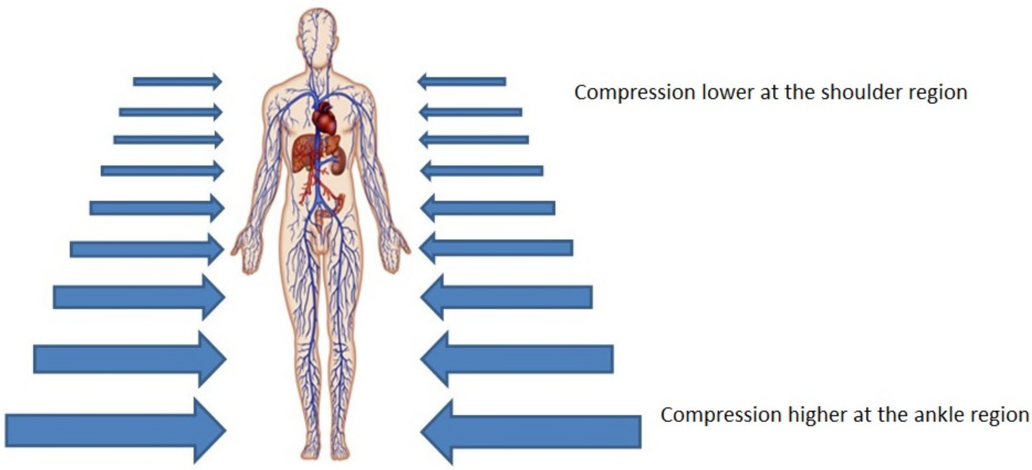

Figure 2 Vascular system and compression pressure gradient – highest at the lower limb and lowest at the shoulder region

Source: Shutterstock

Compression therapy is based on the Laplace equation which states that pressure is directly proportional to the amount of tension and number of layers applied and inversely proportional to the limb circumference and width of the material applied. The effectiveness of compression therapy is well documented. However, the effectiveness of compression garments remains elusive and fragmented. A graduated compression is required to encourage the blood flow from the lower limb toward the heart (Figure 2). Unlike compression therapy, which is intended to aid the return of venous blood by applying sustained and gradual pressure to lower limbs, the claims for compression garments are over optimistic ranging from improved performance of athletes to accelerated recovery following an injury. It should be noted that garments applying pressure locally on the body can only support physiological processes (increased blood circulation or assisting the recovery of muscle injury) and cannot be guaranteed to enhance and accelerate the performance of athletes, as there are many variables that can affect an athlete’s performance (Figure 3).

Figure 3 Athlete wearing compression sports bra and tights
Source: Shutterstock

More frequently, elite athletes are determined to achieve personal bests, including the breaking of world records at each competitive event. Compression was used since the 19th century to treat medical ailments (Thomas, 1998 and Ramelet, 2002) and has featured increasingly since the 1980's, when the use of fabrics with elastane gained popularity. The chapter also discusses the benefits and limitations of compression garments used for sportswear. The benefits of compression garments are physiological as well as psychological and evidence from studies is critically evaluated for its usefulness.

Figure 4 Typical compression base layer clothing (tops and tights)

Source: Dreamstime.com

A typical compression garments has an intimate and anatomical fit (Figure 4), provides support by applying pressure to muscles, increases blood circulation, and reduces blood lactate levels. Athletes require healthy venous blood return. Figure 5.1 and 5.2 draw attention to observations that athletes frequently incur hamstring injury and calf sprain if no garment support is worn.

Figure 5.1 Sports injury with running man

Source: Shutterstock, Inc.

Figure 5.2 Sports injury with running man

Source: Shutterstock, Inc.

4.0 COMPRESSION FOR MEDICAL USES

It is interesting to note that although compression therapy has been widely used in healthcare since the 19th Century (Thomas, 1998; Ramelet, 2002), the use of bandages for venous diseases can be dated to 450 - 350 B.C. (Van Geest et al., 2003). Medical practice has found the use of graduated compression favourable particularly as it works with the muscles to encourage blood flow toward the heart (Moffatt et al., 2007). Other notable benefits of compression therapy are:

- absorption of exudate (fluid) from the wound (Thomas et al., 2007);
- reduction of scar size and improvement of scar appearance (Wienert, 2003); and
- relieve the symptoms associated with venous disease (Moffatt et al., 2008, pp.339)

Compression therapy is achieved using two methods, either by traditional bandaging techniques or by specially manufactured garments such as Medical Elastic Compression Stockings (MECS) (Ramelet, 2002; Van Geest et al, 2003; URGO Medical, 2010). Van Geest et al. (2003) explained how these categories can be classified as elastic or inelastic. Although inelastic bandages may be worn for 24 hours due to low resting pressure, elastic compression should be removed during a 24-hour period to avoid pressure sores resulting from constant compression.

Inelastic bandage, also known as short-stretch bandage, applies light pressure for a short period of time and. Due to their inability to conform to the leg shape, much of the pressure applied decreases over time (Ramelet, 2002; Moffatt et al., 2008). Elastic, or long-stretch bandages, sustain pressure provided for a longer period of time due to the flexibility of the structure (Moffatt et al, 2008), however they are more likely to cause discomfort to the wearer (Ramelet, 2002).

MECS are available in a variety of lengths dependent on the requirement of the user. MECS are classified for prescription with the pressure delivered to the ankle varying from 10 mmHg to ≥49 mmHg depending on the treatment necessary (Van Geest, 2003). Van Geest el al. (2003) reported the classification of the Medical Elastic Compression System (MECS) as light (10-14 mm Hg), mild (15-21 mm Hg), moderate (23-32 mm Hg), 34-46 (mm Hg) and very strong (≥ 49 mm Hg). Current classifications of bandages do not solely incorporate those for compression. Made to measure MECS is recommended for those patients who have very specific needs in terms of fit (Ramelet, 2002). Additionally, ready to wear versions are available in a range of classifications. Ramelet (2002) explained that some patients find MECS hard to wear, particularly the higher classification garments, however devices are available to help this and are generally well tolerated.

Although bandages and MECS are the most commonly used forms of compression therapy in medicine, the use of other compression clothing is often associated with the treatment of burns and hypertrophic scarring. Its successful use was investigated in the early 1970's (Wiernert, 2003). Wiernert (2003) reported how compression clothing is available in many forms including all-in-one body suits, and gloves and is habitually worn throughout the day.

The discussion on the effectiveness of compression therapy for medical ailment is apparent (Weller et al., 2010; Feist et al., 2011; Miller, 2011). Watkins (2010) highlighted the importance of ensuring each patient is wearing the correct size compression garment. Miller (2011) pointed out the need for a standardised method for measuring limbs, mainly to ensure patients are fitted correctly. The lack of fit not only is a cause of discomfort for the wearer but can also result in the lack of desired amount of pressure applied, thus it could harm rather than treat. Watkins (2010) also explained how a patient's limbs can be measured for post-operative compression garments prior to surgery unless a significant change in body shape or size is predicted.

Feist et al. (2011) and Miller (2011) have reported that in order to achieve complete cure through compression therapy, patient adherence is significant, although discomfort was regarded as one of the main reasons why patients fail to comply with the treatment. Miller (2011) explained that patient awareness is a key factor for a successful treatment. Understanding compression therapy with regard to how long patients must wear bandages or garments and possible problems resulting from removing them prior to this were not highlighted in the majority of cases observed. Furthermore, 100% of the cases observed did not receive any written information relating to compliance. Venkatraman et al. (2005) studied the importance of patient compliance and awareness of compression therapy using a questionnaire in determining the effectiveness of compression modality. However, the continued success of compression therapy is perhaps the main reason as to why sportswear manufacturers began to incorporate similar theory into sporting apparel. The expansion of compression garments in the sportswear market is apparent and growing.

5.0 EVALUATION OF COMPRESSION FOR SPORTSWEAR

Compression garments for sportswear and leisure applications have become widely available, providing increased comfort, fit and muscle support. Voyce et al. (2005) reported that human skin stretches considerably, especially 35 to 45 % at knee and elbow regions and extensible garments are essential to provide comfort during intense body stretch (Figure 6). Normal body movement expands the skin by 10 to 50% and strenuous movements in sports are facilitated by low resistance from garments and instant recovery. The knitted fabrics are designed in such a way that they possess elastic property so that the garment offers compression and stretch in both lengthwise and crosswise directions.

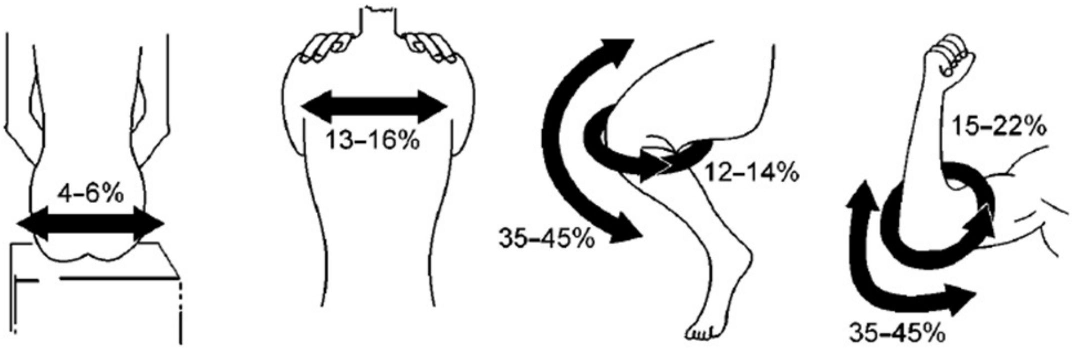

Figure 6: Key Areas of Stretch
Source: (Voyce et al, 2005)

In addition, it is important to note that an athlete will stretch in various ways depending on body movement which is highlighted in Figure 7. Different stretch positions include leg, lower back, thighs, shoulders, abdomen, arms, etc. A compression garment should support numerous different muscles during intense physical activity (Figure 8).

Figure 7 Different type of body stretch

Source: Shutterstock, Inc.

A number of brands have promoted compression wearables such as SKINS, 2XU, CEP, Zensah, CW-X and compression-x. Application of compression sportswear in major events were widespread, for instance in 2000 Olympic Games at Sydney, the sports enthusiasts were focussed on Fastskin swimsuits which were both praised and criticised during the games. The skin-tight compression body suits by Speedo, which aimed to reduce drag whilst allowing full body movement, were worn by almost 85% of the gold medal winners in swimming during the games (Swim-Faster.com, 2012). Craik (2011) reported that the controversy surrounding the suits, which gave the wearers an increased ability to break personal best and world records, led to its ban during 2010. However, this ban was not enforced until after much development of the suits and the introduction of other models including the Fastskin FSII, Fastskin FS-PRO and most notably the “world’s fastest” suit the LZR Racer Suit (McKeegan, 2008). Speedo’s LZR Racer which is made from an ultra-light weight fabric called LZR pulse has low drag and is both water repellent and fast-drying. It was worn by the majority of medal winners at Beijing 2008, including US swimmer Michael Phelps who tallied up a collection of eight gold medals.

Cipriani et al. (2014) investigated the opinion of experienced cyclists on the perceived influence of a ‘posture cueing shirt’ on comfort and recovery. It was found that the athletes’ reported increased benefits in riding posture, post-ride posture, spine discomfort and recovery. Duffield et al., (2010) reported that muscle recovery after sprinting and exercise over 24 hours showed minimal effect on performance, but lowered levels of muscle soreness. It can be noted that compression garments assist in posture support, post-training muscle recovery and reducing muscle soreness.

Figure 8 Athlete wearing compression garment preparing to launch

Source: Shutterstock

Compression garments not only sparked media attention in swimming at this time but also in other sports including track and field. The all-in-one head to toe Nike Swift Suit, aims to provide athletes, in a way similar to swimsuits with reduced drag and increasing aerodynamics (Bondy, 2000). American athlete, Marion Jones, wore a Nike suit to run competitively (Mayes, 2010) however, the trend for head to toe suits for running events does not seem to have the prolonged success as with swimming. Similarly, Nike Swift Suits were used in other sport disciplines, including speed skating and cycling, and demonstrated positive effects (Voyce et al., 2005).

The introduction of compression T-shirts was well received by Rugby players (Voyce et al., 2005). The much tighter fit of the shirts, compared to the traditional rugby jersey, meant that not only the players benefitted by the compression physically, but also other players could not easily grip the tops. McCurry (2004), Shishoo (2005), Cole (2008) and Mintel (2009) stated that public demand for performance sportswear has increased in recent years and all note a rise in compression garments being sold. Walzer (2004) described how compression garments have advanced since the 1990s to include a wider variation of products and colours for all genders, identifying factors that explain the greater demand for such products.

Cortad (2011) reported that although the new garment ‘Quicksilver’ has the conventional appearance of board shorts, there is a hidden compressive short underneath with taping ergonomically positioned to support muscles. The shorts, which utilise the technology usually seen in other sports, are proving successful with surfing championss wearing them. Quicksilver explosive technology uses a 4-way stretch dobby fabric that has less contact with the skin, promotes blood flow, increases lymphatic drainage and supports muscle recovery (Explosive boardshorts, 2015). Furthermore, compression sportswear garments are diversifying. Proskins (2012) have created a range of compression clothing with ingredients such as caffeine and vitamin E incorporated into the fabric to help reduce cellulite. Proskins is marketed for use as day-to-day clothing as well as for sports training. As the compression market continues to grow in popularity in both the professional and consumer markets, the benefits often cited in marketing are continually questioned.

5.1 EFFECTS OF USING COMPRESSION GARMENTS

In the following section, various research reports were critically reviewed on the effects of using compression garments during sports and exercise. As has been noted there is an increasing trend to wear compression sportswear for increasing blood flow and aid muscles whilst training. However, there is much debate over the effectiveness of wearing such garments for sporting activities. Many compression sportswear companies claim that the garments will: improve circulation; improve performance; and reduce recovery times (2XU Pty Ltd, 2009; and Skins™, 2012).

These claims have led to a plethora of research in the area. But there still needs to be a holistic agreement on the benefits of performance and recovery because of conflicting results emerging from many of the investigations. Brophy Williams et al., (2014) used a strain gauge to assess changes in limb volume among active males while wearing a compression socks, legging or no compression garment. They reported that both compression leggings and socks are effective in reducing the limb swelling and further investigation was required to assess whether these changes affect exercise recovery. The above study indicated that the compression garments has an effect on blood flow particularly in the lower limb. Hill et al., (2014) reported a meta-analysis to investigate the effects of compression garments on recovery following exercise. They evaluated 12 studies where assessments were taken at 24, 48 and 72 hours post exercise regime. The research concluded that compression garments were effective in enhancing recovery from muscle damage.

de Glanville and Hamlin (2012) investigated the effect of wearing graduated compression garments during recovery on subsequent 40-km time trial performance. During the study, the participants wore either a graduated full-leg-length compressive garment (76% Meryl elastane, 24% lycra) or a similar-looking non-compressive placebo garment (92% polyester, 8% spandex) continuously for 24 hours after performing an initial 40-km time trial in their normal cycling attire. The participants had a second trial with garments following 24-hour recovery period. A week later, the groups were reversed and tests repeated. The performance time in the second trial was substantially improved with compression garments compared to placebo garments. The researchers concluded that graduated compression garments during recovery are useful and less likely to be harmful for well-trained endurance athletes. Compression garments can influence the wearer proprioception (which is an unconscious perception of movement and spatial orientation arising from stimuli within the body itself). Hooper et al., (2015) investigated whether wearing compression garments would enhance proprioception and comfort affecting sports performance especially on high-level athletes. The athletes were involved in baseball and golf activities who wore either a compression garment or a non-compression garment. Researchers reported that comfort and performance can be improved with the use of compression garments in high-level athletes and is most likely to be influenced by improved proprioceptive cues especially while engaging in upper body movements.

Luke and Sanderson (2014) undertook a meta-analysis to determine whether wearing compression clothing affect the athletic performance by increasing endurance and aerobic activity as measured using VO2 max [maximum oxygen consumption/uptake] and heart rate. They included only those studies that examined continuous running. Of the four studies considered, only one concluded that wearing compression garments improve performance, and three studies reported that compression garments were highly effective in reducing muscle soreness and oedema. The authors concluded that wearing lower extremity compression socks can be very effective in reducing oedema during or after exercise.

Duffield and Portus (2007) monitored the effects of full body compression garments. Participants in the study completed a series of distance and accuracy throwing tests along with sprints in either a control garment or one of three brands of full body compression garments. However, there were no significant differences between the control condition and the three brands of compression garment. Hill et al., (2014a) investigated the efficacy of a lower limb compression garment in accelerating recovery from a marathon run among 24 subjects who were assigned as ‘treatment’ and ‘sham’ group. The researchers reported that lower limb compression garment improved subjective perceptions of recovery. However there were neither improvement in muscular strength nor significant changes in exercise induced muscle damage and inflammation. There were other studies that demonstrated small benefits to performance (Doan et al., 2003). Sperlich et al., (2010) observed the differences to performance benefits of compression socks, compression tights, whole body compression garments and control running clothing. All fifteen participants completed running tests on a treadmill in each type of clothing. Performance was measured by monitoring lactate concentration and oxygen uptake. There were no performance benefits observed when wearing compression garments.

Twenty track athletes completed a series of tests to measure sprint times, muscle oscillation and jump power in both loose gym shorts and compression shorts. The jump heights recorded was increased by 2.4 cm when wearing the compression garment. There were some noticeable benefits while wearing compression stockings on performance (Doan et al., 2003). Ali et al. (2011) investigated the effect of varying the level of compression stockings (low, medium and high) during a series of countermovement jumps before and after running trials. It was found that the changes in jump height from before to after exercise were much bigger when wearing the low and medium stockings compared to when wearing a control garment. Miyamoto et al. (2011) focused on the effect of compression on torque of the triceps muscle. Triplet torque was monitored both before and after calf raise exercises and there was a smaller reduction of power after exercise when wearing the compression stocking with 30mmHg at the ankle. However, there was no evidence for the 18mmHg ankle stockings having any effects.

Other studies also reported some benefits of wearing compression garments among athletes who participated in circuit training, that included sprint times, flight times and jump height (Higgins et al., 2009), reduced injury and recovery time (Rogers, 2012), improved recovery following exercise induced muscle damage (Jakeman et al., 2010). Compression garments were used as a recovery tool for a three-day exercise protocol. The use of cold water bathing and carbohydrate consumption along with post exercise stretching were two other conditions for the investigation. Under these circumstances, cold water bathing was deemed to be more beneficial to recovery than the use of compression garments or carbohydrate consumption and post exercise stretching (Montgomery et al., 2008). It can be noticed from the above, that the documented effects of compression garments was not consistent across different sporting activities. It should also be highlighted that the research studies were conducted using different protocols and, in most cases, the changes in sports performance were reported by elite athletes. However, it may be significant that most of the studies reporting benefits relate to blood flow in lower limbs as opposed to upper body movements. Thus, compression appears to be effective in reducing oedema, enhancing muscle recovery and reducing muscle soreness.

6.0 APPLICATIONS OF COMPRESSION GARMENTS IN SPORTSWEAR

In this chapter, specific attention is given to three sports namely, cycling, skiing and rugby. Compression garments have become a staple for athletes’ in these sports, as support is required for muscles continuously, providing aid in reducing muscle fatigue. Areas of importance to these sports are highlighted in the section below and in Figure 9.

6.1 CYCLING

A wide range of compression wear is available for professional cycling and is elaborated in Venkatraman et al. (2013). Leg muscles are the main source of power and endurance. During cycling a cyclist uses the following set of muscles:

- **Gluteal muscles –** bottom area pushing pedals at the top of a stroke.
- **Quadriceps –** large muscles at the front of thigh that straighten the leg when pushing the pedal down to the ground
- **Calf muscles –** Ankle movement and calf muscles facilitate return of blood from lower limbs, when the heel strikes the ground (Morrison et al., 1998). Hence good ankle movement facilitated by calf muscles only achieves a healthy venous return.
- **Hamstrings –** located at the back of the thigh, working with calf muscles lifting the pedals up from the bottom of a stroke.

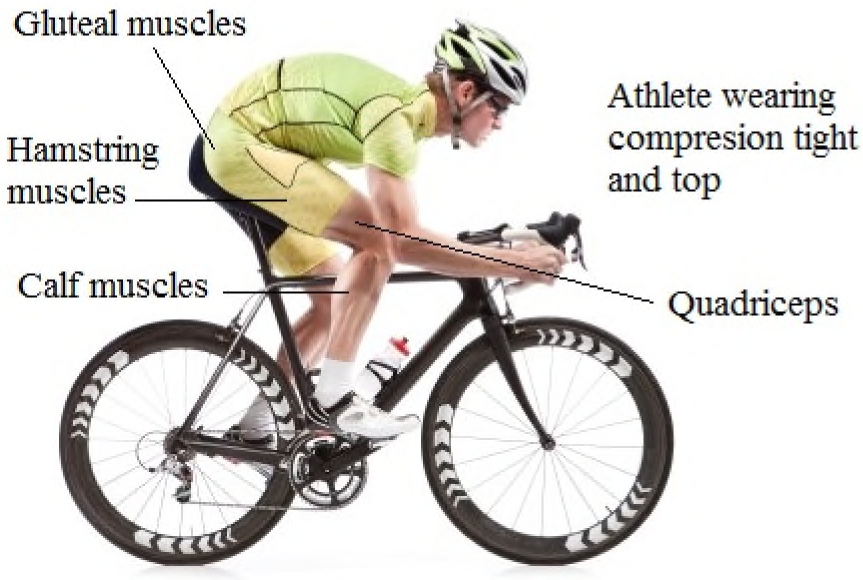

Figure 9 A cyclist in action wearing a compression garment

Image: Istockphoto

There are support muscles working together with leg muscles, such as upper muscles engaging with the handlebar. There use is terrain dependent. For example, a hill climb will increase handlebar pressure so the biceps are used to enhance power. Back and abdominal muscles are also important to stabilise cyclists whilst riding (Yake, 2011). A range of garments are available for professional cycling; including sleeve jersey, sleeveless jersey, long sleeve jersey, jacket, vest, long and short sleeve skin suits, bib shorts, tights and knickers. Recently, Venkatraman et al. (2013) critically appraised the specifics of cycling compression garments – including, requirements of garments/fabrics, fabric panels to support muscle groups. In addition, consumer perspectives on using compression tights for cycling were also described.

6.2 SKIING

Compression base layer tights for skiing help to regulate body temperature, support muscles, aid in blood circulation, support in muscle recovery and fatigue. By reducing the amount of lactic acid in the tissue during and after a physical activity the athlete’s recovery is greatly enhanced and prevents soft tissue injury. Typical base layer garments for skiing include full sleeve tops, tights and one-piece garments that cover torso, arms and legs (Figure 10). A ski base layer compression garment keeps the wearer warm in cold conditions as well as supports muscle movements.

Figure 10 Mathias Elmar Graf (Austria) places third in the men's slalom, on January 21, 2012 in Patscherkofel, Austria.

Source: Shutterstock, Inc.

Figure 11 Typical requirements of skiing compression base layer

The garments are generally made of synthetic fibre blends or wool fibre blends. The fabric is intended to be lightweight, soft next to the skin, abrasion resistant, and some of the features of a typical compression base layer for skiing are highlighted above. Skiing base layer compression tights are constructed from a lightweight knitted fabric that is brushed inside to provide comfort to the wearer. In addition, the fabric is wind and water proof and able to wick moisture away from the skin. The fabric has plenty of stretch as it composes of 10 to 40% elastomeric filaments and 90 to 60% synthetic filaments (nylon or polyester). The garment is commonly sewn using flat lock seams for additional comfort. To reduce chaffing seamless garments are preferred. Typical requirements of a ski wear is highlighted in Figure 11.

Figure 12 Rugby player wearing compression tops and tights
Source: Shutterstock

6.3 RUGBY SPORT

Rugby is a high contact sport where one in four rugby players will be injured during a season. Rugby injuries are three times higher in football. Most injuries are experienced by youth 10-18 years and adults aged 25-34 years of age. Figure 12 shows a typical player wearing a compression garment. In rugby, 57% of most sport injuries occur during matches rather than in training and particularly when a player tackles or is being tackled (South Wales Osteopathic Society, 2009). Hence, most compression garment will have protective pads in tops (Figure 13) and shorts. The range of compression garments for rugby include sleeve tops, full sleeve tops, shorts, tights, calf sleeve, and socks.

Figure 13: Typical tops for rugby with impact protection pads

Reported benefits of compression wear in rugby

- Reduce muscle soreness and swelling
- Reducing muscle oscillation during a vertical jump or fall
- Increase VO_2 max [a physiological index of sports performance]
- Reduce collection of blood lactate levels in the tissue
- Reduce muscle injury or cramps

The use of tapes and compression may assist in muscle recovery and keep the body in a safe position during contact sports such as rugby. In rugby, adults endure more injuries to head, shoulder and lower limb (thigh) whereas children suffer from head/neck injuries followed by upper and lower limb (www.injuryresearch.bc.ca).

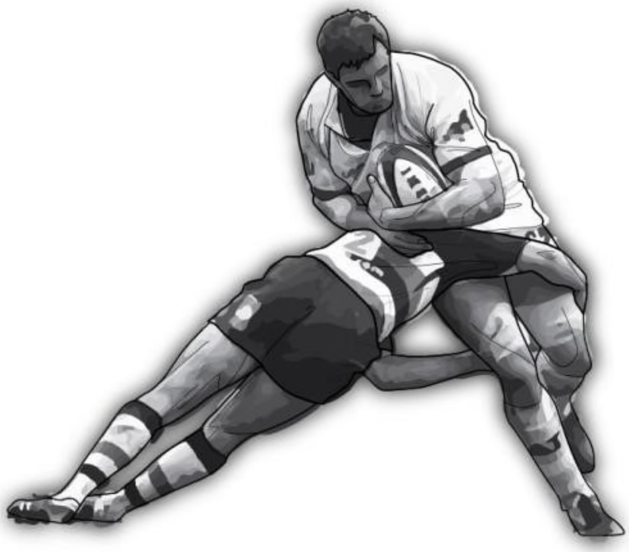

Figure 14: Rugby player tackling
(Source: Author's own image)

Approximately half of all injuries occur while a player is tackling (Figure 14) or being tackled. Hookers and flankers sustain the most injuries. Forwards are more frequently injured than backs because of their greater involvement in physical collisions and tackles (British Columbia Injury Research and Prevention Unit, 2012). Due to the nature of injuries sustained, clubs may frequently lose players from sports participation, hence they are under pressure to prevent or reduce injuries to its players by requiring them to wear a protective gear. Table 1 highlight some of the popular brands for cycling, rugby and skiing.

Table 1: Market brands: compression base layer

Compression wear	Popular brands	Major claim	Specific feature
Cycling	Adidas Bibshorts	British cycling brand for added comfort and fit	82% polyester and 18% elastane, silicone elastic gripper on hem for perfect fit and mesh strap in shoulder and synthetic chamois padding
	Dhb Vaeon Roubaix padded bib tights	Anatomical fit, light weight, thermal insulation	Breathable, made of 85% nylon and 15% elastane; brushed inner side
	Castelli Garmin Sanremo Speedsuit	Body paint speed suit; seamless and integrated cushion seat pad	Integrated grippers no seams to avoid chaffing, flat lock seams, four way stretch fabric.
	Altura	Cool mesh bibs and a ProGel seat pad for cushioning and comfort	Light weight stretch fabric, breathable, anti-bacterial and silicone grippers
	Assos tights	F1 Uno_S5 seat pad, an Anatomic six panel cut for added comfort and performance	75% nylon and 25% elastane; shock absorbent foam cushioning that is bonded onto the elastic, frictionless, skin contact textile.
	Giordana	Fusion bib shorts with great fit, supports a range of body motion	Made of Moxie fabric, a light weight, breathable, with micro mesh for ventilation, with silicone injected grippers
	Gore Bike Wear	Oxygen waist shorts: High-end padded cycling tights for the medium to long distance road cyclist.	Offer high functionality and comfort. A reinforced inner leg panels and an Ozon seat pad for comfort, durability and longevity

Rugby	Canterbury	Mercury TCR compression – Legging - reduces muscle oscillation by compression at key zones in lower limb	Made of coolmax polyester 74.5% and 25.5% Lycra; moisture management; flat seams and anti-bacterial; reduced seams for added comfort.
	Nike Pro	Pro-direct compression tops with dri-fit fabric	Moisture management; flat tape at shoulders to reduce friction; mesh panels at under arm and flat seams to prevent chaffing.
	Kooga	Tops - EVX protection offers the optimum fit and freedom of movement.	The pads consist of a lycra body, shoulder, sternum, bicep padding, all comprised of high expanded EVA.
	2XU	2XU Mens Elite Compression Top for athletes requiring more power and support.	Garment helps to reduce muscle fatigue and damage. The graduated fit supports in increasing blood circulation.
	There are other popular brands such as skins, BSc, Odlo, Under Armour, Red Ram and Helly Hansen for rugby.		
Skiing	Skins	Skins S400 long sleeved top offers comfortable and precise fit coupled with engineered gradient compression to create the ideal compression garment for colder activities such as skiing,	Warp knit fabric; brushed inner side; thermal insulation; moisture management; anti-bacterial; UV protection;
	CWX	Stabilyx Tights target – lower back/core and knee joint and surrounding muscles for stability during skiing.	Made of 80% polyester and 20% elastane; designed to reduce the quick build-up of lactic acid in the muscles, whilst keeping comfortable and dry during exercise by wicking moisture away. Body moulded compression garments improve recovery after periods of sustained exercise.

Source: Various

It can be observed that popular brands for compression wear claim specific support for muscles, reduced muscle oscillation, improved recovery, the ability to target specific muscle groups, involving grippers to prevent chaffing, and lightweight fabric that is breathable, moisture wicking and provides thermal insulation. In addition to the compression, comfort and fit plays a vital role in designing the garment. In the case of cycling, prominent features include, an integrated bib shorts seat pad cushion and provision of mesh shoulder panels. In rugby, to protect from soft injury, pads are integrated in the tops while the tights use quick dry technology. Finally, skiing garments focus on stability, targeting muscles in lower back, hamstring, and knee joint and providing ankle support. In addition, most fabrics have anti-bacterial, anti-odour and UV protection finish applied.

7.0 MARKET TRENDS IN COMPRESSION SPORTSWEAR

Trend Insight is a feature in Outdoor Insight that includes consumer research and retail point-of-sale data from The Leisure Trends Group. Its recent report stated that commonly purchased compression items were tights/capri tights, sport tops/bra tops, shorts, socks and arm/leg sleeves (www.leisuretrends.com).

According to a recent report by Leisure Trends Group's Running RetailTRAK™ that traced sales in the compression apparel category, compression apparel and apparel accessories grew 56% in 2009 and 170% in 2008. Tights were the largest compression category for runners during 2010, followed by arm/leg sleeves. Other compression categories included capri tights, sport tops/bra tops, shorts and socks. Women’s apparel styles outsell men’s in running speciality and this trend holds true with compression. While woman-specific shorts and capris are larger in terms of overall volume, especially compression sports bras and sport tops in 2011, with leading brands such as Zensah and Nike (www.leisuretrends.com).

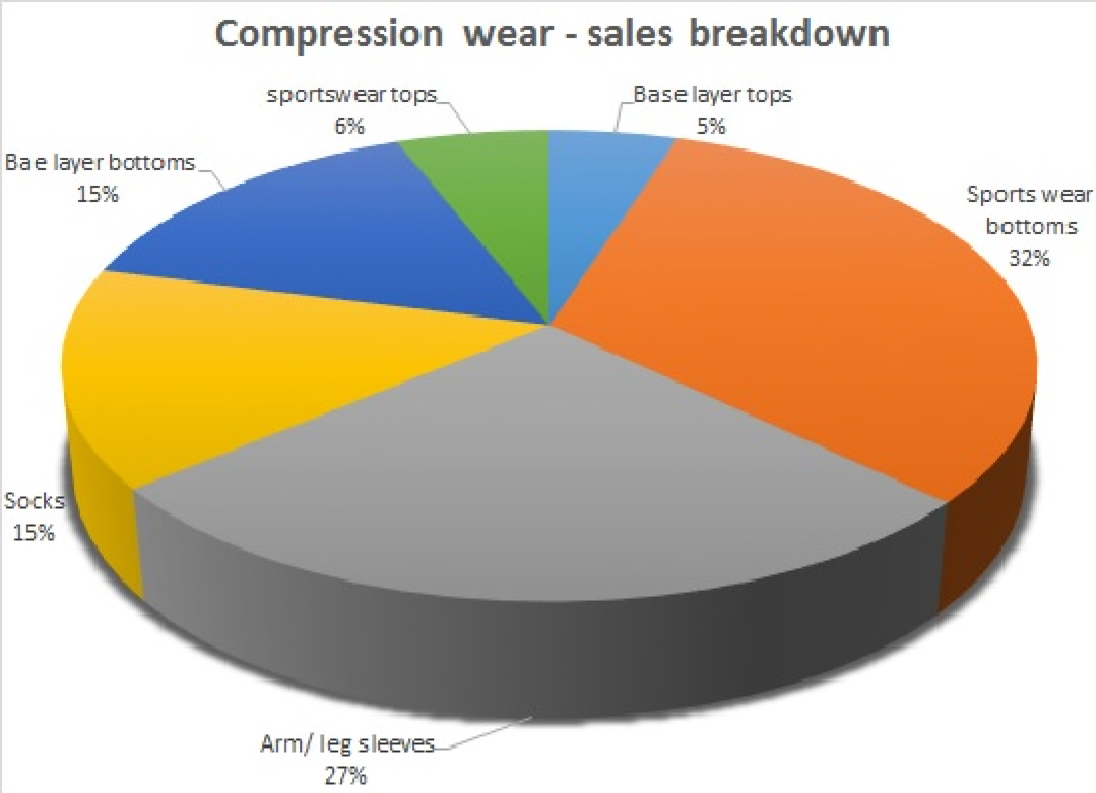

Figure 15 Compression Wear: Breakdown of sales (2010)

Source: Trend Insight, April 2011

It can be noted that tights for bottoms (lower limbs) were frequently purchased (32%) followed by arms or leg sleeves (27%). In addition, compression socks were also widely preferred (15%) followed by base layer bottoms (Figure 15).

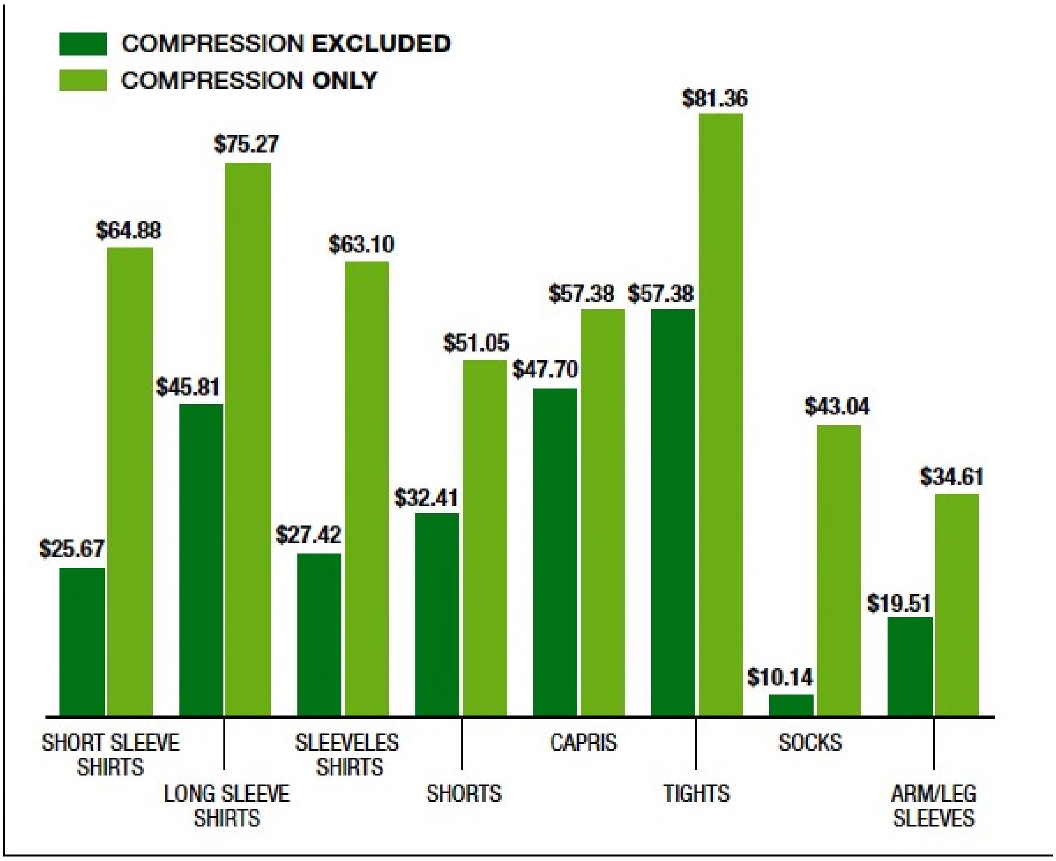

Figure 16 Average Retail Selling Price – Compression Garments

Source: Trend Insight, April 2011

The above chart shows that compression garments are preferred when compared to non-compression sportswear. This is true for short/long sleeve shirts, sleeveless shirts, shorts, tights, socks and arm or leg sleeves. The retail price for compression garments is 1.25 – 2.5 times higher in price than non-compression wear, but in the case of socks the prices are four time higher than normal socks, as highlighted in Figure 16. The market trend for compression wear has been steadily increasing since 2008; the apparel market has fared better compared to socks and sleeves for arms/legs. The overall market size in 2010 for all compression wear was $ 8.4 million as opposed to $ 3.1 million in 2008. Hence, it is predicted that the market will continue to increase with new developments in fabric and garment technologies for a number of sports.

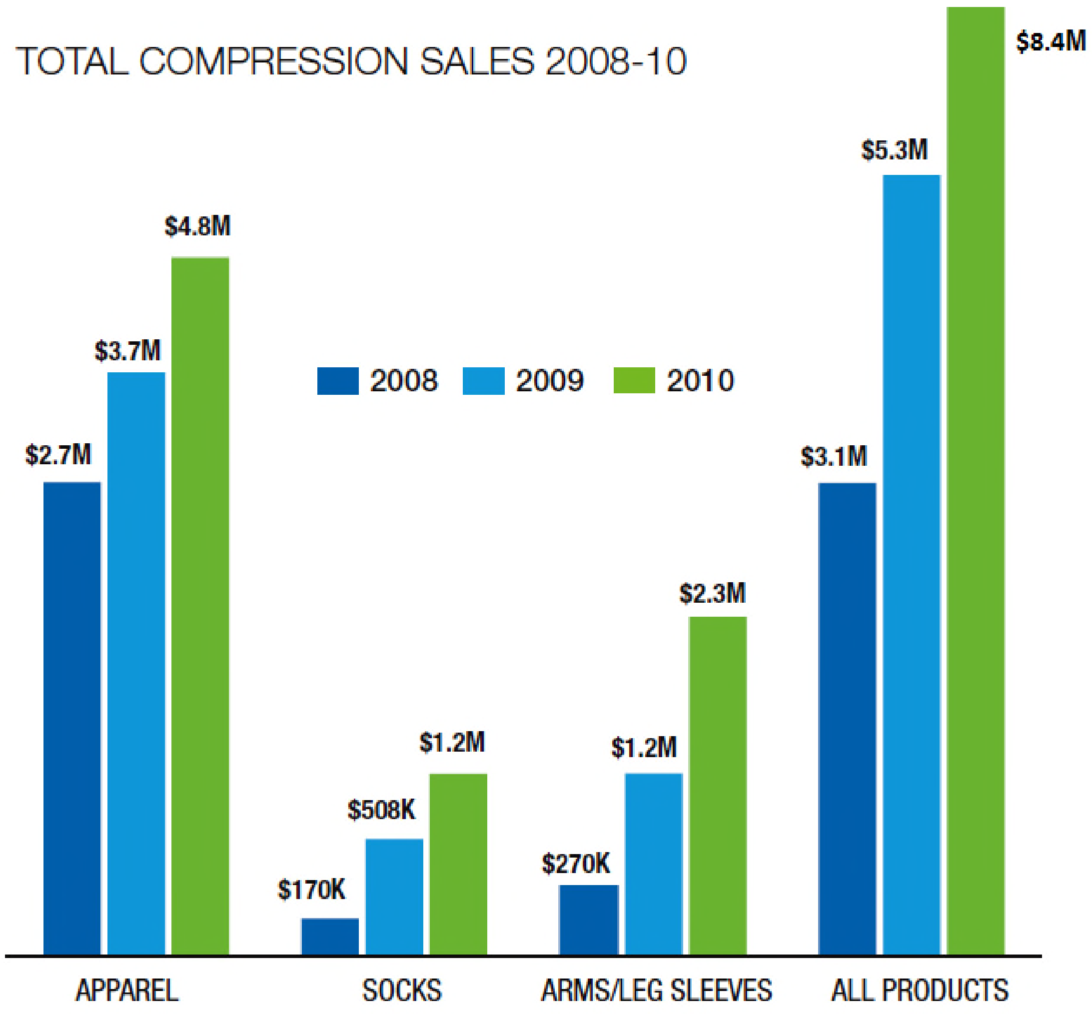

Figure 17 Compression wear sales

Source: Trend Insight, 2011

It can be observed from Figure 17 that compression garments in the form of apparel frequently purchased compared to socks and arm or leg sleeves. The market trend is predicted to grow rapidly due to a number of factors such as increase in sports participation, and athletes being educating oneself about care products such as a compression wear. It is also anticipated that due to rapid developments in the field of smart textiles, a number of new and innovative materials will emerge in the future creating a plethora of products to choose from for a sporting activity.

8.0 CONTEXTUAL FACTORS AFFECTING COMPRESSION GARMENT PERFORMANCE

The following section highlights some of the factors that affect the application of compression (Figure 18).

- Pressure applied by the garment (support specific muscle groups)
- Graduated compression (maximum pressure at the extremities and decline in pressure closer to heart – see Figure 2)
- Fabric offers sufficient stretch and recovery at the key points – knees, elbows, buttocks, shoulder, and arms

For instance, in cycling the athlete requires endurance and preparation, and there are many factors affecting the overall performance of the wearer. Three core factors have been highlighted, clothing/material worn athlete's capabilities and the intensity of the sport. Compression garments are designed to provide intimate contact with the human skin; hence there is interaction of garment with athlete. This obviously depends on the musculature, microclimate of the fabric, and physiological response of the athlete that depends on the intensity of the sport. In addition to the above, there are three major contextual factors that affect compression garment development. These are discussed

below.

Figure 18 Factors affecting sports performance

8.1 GARMENT SIZING

Designing compression garments for various body shapes and body type is a complex procedure. It should be noted that most brands develop sizes based on fit athletes or specific target population. Grading of compression garments for creating various sizes (small, medium, large and ex-large) has created a challenge in garment manufacturing by using size charts derived from anthropmetric studies (Allsop, 2012). Le Pechoux and Ghosh (2002) reported that consumers were often unhappy because of the large variations between sizes of different brands or in different retail outlets. Loker (2007), reported that sizes are developed on the basis of large anthropometric studies with sample representing the entire target population. Such anthropometric studies have benefitted from 3D body scanners in recent years to reduce the time taken to collate body measurements. However, they are expensive and time consuming to conduct (Le Pechoux and Ghosh, 2002; Yu, 2004; Loker, 2007; Otieno, 2008). Le Pechoux and Ghosh (2002) stressed that variations between gender, race and generations are apparent through studies on body shape. It could be noted that in the case of the medical compression garments (JOBST), specific measurements of consumers are taken using a body measurement chart to produce a close fit to the body shape and size (Absolute Medical, 2014). Certain sports companies such as Giordana (2013) also produce custom-made cyclist compression garments such as bib tights, long and short sleeve jerseys, socks, etc. that provides good fit. Some firms also offer custom-made socks, pro-calf tube, hamstring tube and ankle socks (UKsportsproducts.com) and compression leggings and tops that offer optimum pressure distribution (Kurioperformance.com). It should be noted that in the case of stretch garments such as cyclist’s shorts, that closely fits to body contours, the patterns are shaped for the active position so that they fit well when the rider is on the bike (Ashdown, 2011).

Ideally, a compression garment stays close to the skin with a tight fit and has the ability to stretch and recover based on the activity of the wearer. If the garment has a tight fit in resting position, the increase in blood flow during intense activity is likely to increase the volume of limbs and change the perception of overall garment fit. On the other hand, if the compression garment is baggy, it may not apply the desired compression at the region. Hence, it becomes necessary to understand the pressure required at various zones of the garment, garment sizing allowance during manufacturing, and fabric properties during grading of garment sizes.

8.2 BODY SHAPES

Male body shapes are implicitly labelled as: endomorph; mesomorph; and ectomorph. Figure 19 illustrate ectomorph shapes are characterised by being tall, lean builds with little excess body fat. Mesomorph's are a medium build and have a more athletic frame with broad shoulders and a narrow waist. Endomorph shapes have a wider frame and generally more fat. As previously noted, the most common body shapes in a population are affected by many factors including race, gender and life style (Le Pechoux and Ghosh, 2002). Furthermore, although these specific body types are widely recognised many men have variations from these body types. These factors mean that sizing for ready to wear garments can be extremely difficult thus resulting in consumer dissatisfaction. Although custom-made garments produced to specific measurements can ensure a perfect fit, the time and cost to produce such garments is so much that this is not viable for a mass market (Loker, 2007).

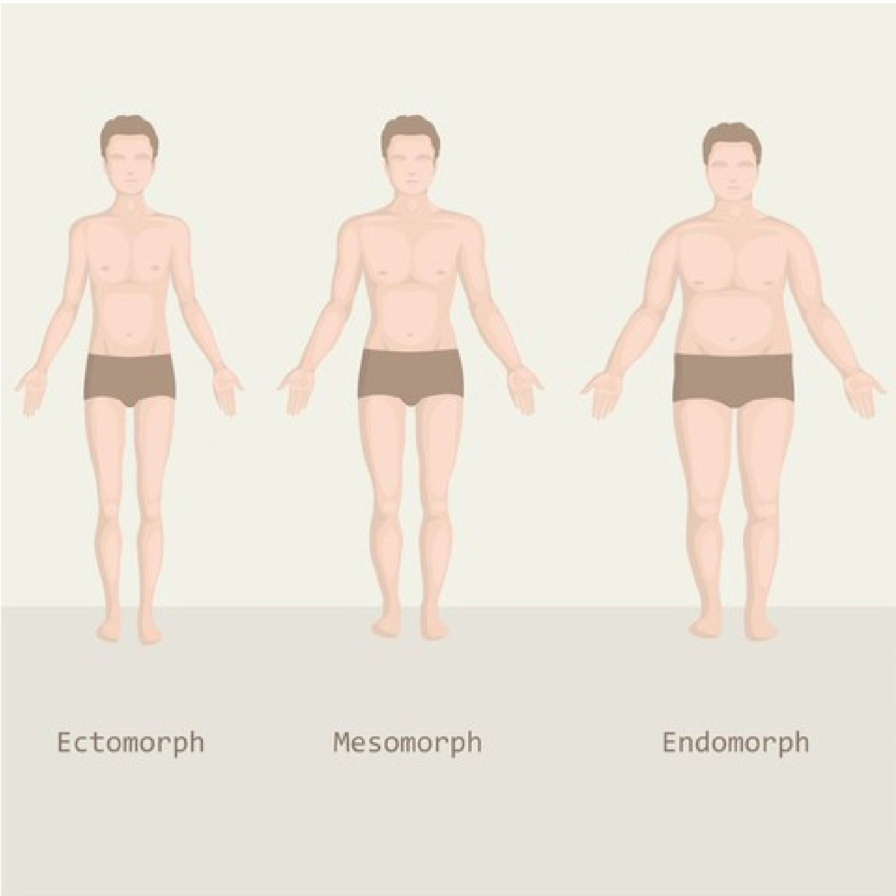

Figure 19 Body types

Source: Dreamstime

8.3 SIZING AND DESIGNING WITH STRETCH FABRICS

A sizing system involves developing a pattern that relate to a fit model and adding a set of graded patterns based on the assumption of proportional measurement changes larger and smaller than the fit model (Branson and Nam, 2007). Generally, a wear ease is allowed for body movement. However, in the case of close fitting garment such as compression garment the wearing ease is negligible as the fabrics stretch because they are made from elastomeric filaments. The patterns developed for stretch fabrics are smaller than patterns created for non-stretch woven fabrics, in other words, patterns are smaller than the body measurements. Therefore, patterns developed for stretch fabrics are often complex and it is necessary to know the fabric behaviour. Yu (2004a) stated that it is incorrect to assume that stretch fabric garment will automatically fit the body contour in all places and provide ease of body movement. Hunter and Fan (2004) identified that fabric properties (bending property, formability, and fabric thickness) affect the fit, sizing, and seam quality. In addition, the usage of garments following washing also contributes to shrinkage or growth, which can affect close fitting compression garments. Hardaker and Fozzard (1997) also highlighted the importance of appropriate fabric selection, as an inappropriate fabric may send production back to early stages of product development. The designer should have a good understanding of the fabric behaviour and characteristics, because this fabric knowledge will affect the garment grading especially in determining the increase or decrease of patterns derived from body measurements and size charts.

8.4 FABRIC PANELS

Compression garments are usually made of fine knitted fabric that contains 80-75% polyester or nylon and 20-25 % elastomeric filaments, which stretch and recover back to their original shape during physical movements of the body. In a typical flat knit, stretch fabrics can be produced using inlay and body yarn (elastomeric yarn) that imparts stretch-ability to the fabric. A recent US patent (Young, 2009) on the manufacture of compression garment for sportswear highlighted the number of panels required to isolate and support specific muscle groups and aid in blood circulation or assist in reducing soft tissue injury. It also added that panel shapes and seams correspond to various muscle groups for a whole body compression garment.

Table 2 Fabric Panels for specific muscle groups

Front view	Collar bone panel
	Biceps panel
	Elbow panel
	Lower end panel (arm)
	Centre front panel
	Upper limb panel
	Lower limb panel
	Side body panel I and II
	Chest panel
Back view	Back bicep panel
	Back elbow panel
	Lower back end panel
	Lower back limb panel
	Upper back limb panel
	Lower side back panel
	Lower centre panel
	Upper back side body panel
	Upper centre back panel

Figure 20 Human musculature

Source: istockphoto

In order to support the human anatomy various fabric panels of a full-body compression wear are proposed that contains 19 different panels (front and back). Recent research (Allsop, 2012), investigating the pressure profile using Tekscan pressure sensors, identified that when a compression garment made of several panels, that are sewn together, the pressure applied by the garment on to a specific muscle group is not uniform. Hence, the lesser the number of sewn fabric panels the better the pressure applied. This is presented in Figure 21 where fabric panels are designed based on the specific muscle groups identified in Figure 20, Table 2. It could be noted that factors discussed above that affect the compression garment development should be taken into account whilst designing garments.

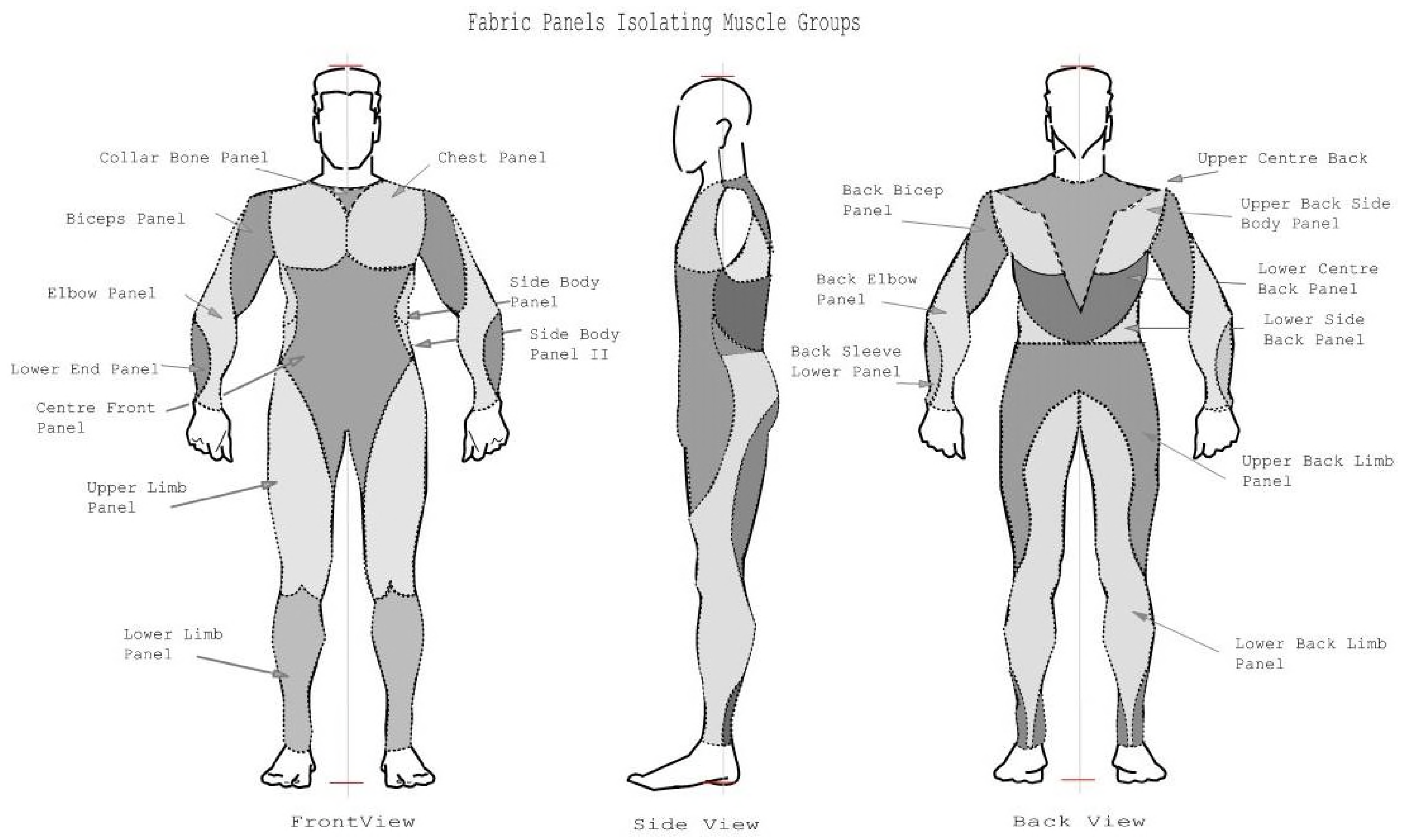

Figure 21 Various fabric panels to support human musculature

Source: Author own image

9.0 SUMMARY AND CONCLUSIONS

Compression for sportswear is a growing market and in recent times, greater awareness among athletes has led to an increased usage in a wide range of sports. Major international events such as Olympics and athletic championships, also have triggered new technological developments in compression garments. New innovative compression garments for sportswear will continue to be developed due to interests from athletes, enthusiasm from amateurs, and demand for casual leisurewear. Compression garments appear not only support with the performance but also more importantly portray professional approach only to sport. In addition, these garments also serve to support body posture whilst training and preparation. Many studies have reported on improved performance characteristics and recovery times of athletes but there is still yet to be a clear understanding of whether compression garments are beneficial. It is difficult to apply some of the research findings, as most studies were conducted in a controlled environment or using a small sample or using professional athletes. A series of claims made by sportswear developers can bewilder consumers in their selection of specific sportswear garment.

Furthermore, some studies have highlighted the importance of determining fabric characteristics that contribute to the pressure distributed on the muscles. Good understanding of fabric characteristics is vital when designing garments with stretch fabrics. Practically, evidence relating to the effectiveness of compression sportswear need to be collated and disseminated to a wider community, so the users will have complete confidence in wearing the compression garments. In addition, there is dearth of information relating to various body shapes and sizing, as research was generally related to fit athletes.

The chapter has highlighted three key sporting applications where compression garments are widely used, cycling, skiing and rugby. In the case of cycling, compression garments focus on the lower limbs, providing specific support to calf muscles, gluteal muscles hamstring and quadriceps. As a rule of thumb, the pressure is applied in a graded way so that the extremities receive slightly more pressure than the regions close to the heart. In the case of skiing, which is a high intensity sport, the garment is required to provide stretch and recovery particularly for knee, elbow, pelvic muscles, lower limbs and arms. In addition, the garment should be regulating moisture and keeping the wearer warm by resisting cold wind penetration. Rugby, unlike cycling and skiing, is a high contact sport, where shoulder/lower limb injuries are often sustained during tackling, hence the key aspect in rugby compression wear is to aid in muscle recovery, prevent soreness, fatigue, reduce blood lactate levels and more importantly offer impact protection to shoulder, arms and sternum (chest).

Various ‘contextual factors’ that influence design and development of compression garment were discussed including number of fabric panels, body shape and sizing, stretch and recovery, and compression applied locally. It should be noted that as the consumer market base is increasing it is necessary to consider various body shapes and size the garments accordingly. The stretch fabrics made of knitted construction requires good knowledge of fabric behaviour, particularly their stretch and recovery property following deformation. Market trends for compression garments are positive. There is an increase in usage, particularly tights that are often sought to facilitate support for lower limbs during intense sport.

A systematic review of evidence was collated relating to compression garments. Although there are convincing benefits from some studies, most research suffer from small sample size and lack of practical significance. Although studies relating to recovery and reduced injury gave positive results, subjects could have been influenced to perform well when they were aware of trials. It should be stated that further work is needed in this area, as evidence is elusive. It can be concluded that users are concerned with garment sizing and comfort, hence further work need to be carried out in developing a precise measure system that will evaluate pressure, comfort and predict using a simulation model by utilising fabric behaviour characterises which would eventually facilitate in garment design and development.

The compression sportswear market is predicted to grow significantly in the next decade or so. The aim of this chapter is to help readers understand the reported benefits of compression and interpret claims of manufacturers, being aware of specific applications of compression wear – cycling, skiing, and rugby, factors that affect compression performance and development, and recent market trends in compression garments.

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