The 5Ps Model to Optimize Compression Athletic Wear Comfort in Sports

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Abstract: Engineered design of compression athletic wear has been selectively applied in various recognized Olympic sports and popular recreational activities. This recent development is, as one type of additional body-behavioural support, protection and adjustment, plays a crucial role, in improving the athletes' performances. Typically, this is accomplished by providing engineered design support, pressure, and form-fit on targeted areas of athletes' body. In the present paper, a contextual model including 5Ps (i.e. Physical, Psychological, Physiological, Psychophysical, and Psychophysiological properties) related to user comfort and performance, has been developed to analyze multiple relationships between the athlete, athletic wear, immediate body space and sports environment, which would help us understand the effects of athletic wear on sports performance. The 5Ps reference model explores the mechanisms of action of body-clothing-environment system from a comprehensive view, thus effectively optimizing functional design of compression athletic wear in practice to enhance sports achievement and comfort.

Keywords: 5Ps model, compression, athletic wear, comfort, sports.

1. Introduction

Growing interest in sports activities and the emergence of new Olympic sports has stimulated and increased the consumption and demanding expectations for athletic wear [1]. Sport is an integral part of every culture and has profound impact on the athlete, national pride, the spectator, and the media. In the United States, participants in running/jogging and treadmill sports increased by 30.8% and 34.3% in 2007 compared to 2000 [2]. Exercise walking is a most popular sport, which has showed a marked ascent since 1993, and team exercise (e.g. basketball, baseball, football, etc.) continues to attract sports participants (Figure 1). Scientific design and development of athletic wear with wearing comfort and satisfactory functionality enhance not only the well-being and health of the athletes, but also their sports performance and records achievement. Engineered design compression athletic wear (CAW) has been selectively applied in various recognized Olympic sports and popular recreational activities, e.g. running, bicycle riding, skating, swimming, gymnastics, rock climbing, football, yoga, etc. The application of CAW has played a crucial part in improving the athletes' performances in speed, body control, stamina, strength and fatigue recovery, etc., by providing engineered design support, pressure and form-fit on targeted areas of the athletics' body [3-4].

Compression athletic wear are usually designed to intimately maintain contact with human skin. The functional performance of athletic wear is largely determined by complex interactions between multiple factors, such as material physical structure and mechanical properties, thermal and moisture regulatory properties, the size and shape of the body to which it is applied, the corresponding dimensions of designed athletic wear, the nature and levels of physical activity undertaken by the athletes, comfort, and sports environment, etc. The comfort status is a subjective perception and judgment of a wearer on the basis of integration of all of these above factors, which has been generally defined as range of physiological, psychological and physical variables and their interactions with environment [5-7]. Most of the competition sports proceed in dynamic states, during which the athlete's body, mental activity, clothing, and near environment generate more complicated interaction and continuous variation. For instance, during intensive training, an athlete's clothing moisture transport ranges from 1.5 to 2.5 litres per hour [8]. In cycling sport, the athletes' metabolic heat increases 6 times and perspiration 14 times more than those engaged in normal routine indoor activity [9]. Hence, the psychological responses of athlete towards the changed physical properties of athletic wear (i.e. psychophysical mechanism) and the physiological activities with the variations of psychological processes (psychophysiological mechanisms) may exert more prominent influence on the overall comfort

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perception of athletes. In the present study, we seek to develop a contextual model that includes the 5Ps, i.e. Physical, Psychological, Physiological, Psychophysical, and Psychophysiological properties related to user comfort, and to present the relationships between the athlete, athletic wear, immediate body space, sports environment, and competition culture. Based on the engineered design athletic wear, how to optimize wearing comfort related to 5Ps are further discussed.

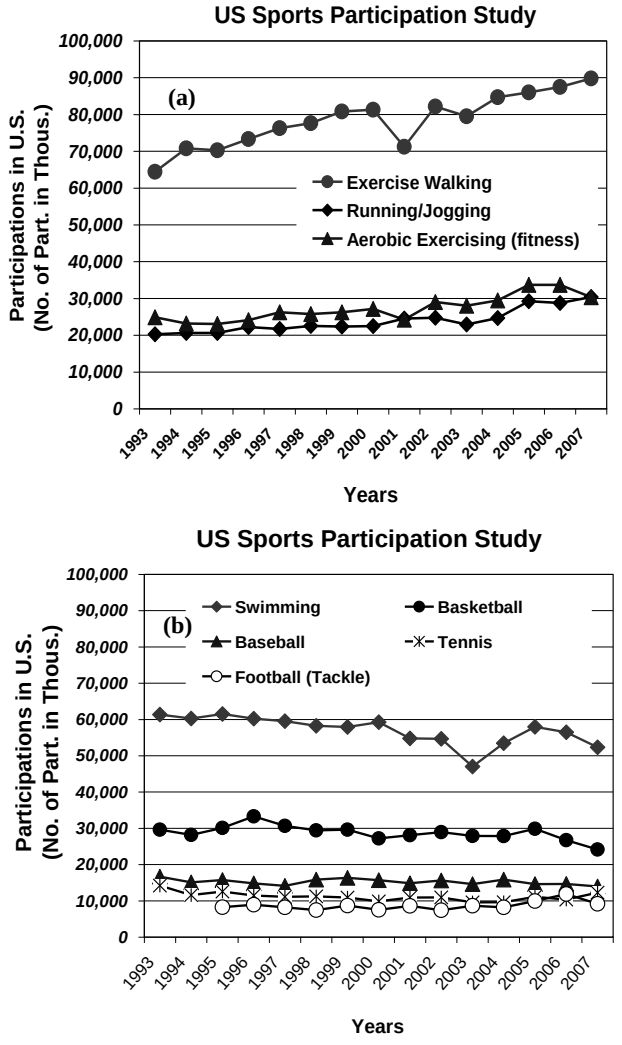

Figure 1 Trends in selected sports participation analyzed over 15-year period in the United States

2. 5Ps Contextual Model for Optimized Performance User Comfort

The developed model as shown in Figure 2 illustrates the factors involved in the multiple layers which are influencing and determining the user comfort.

The multiple layers deal with the following issues:

- An inner layer of engineered static aesthetic design and basic functional properties of athletic wear (i.e. style, colour, dimensions, attributes, panels design, fit, etc.);
- A design layer focused on dynamic functional performance and wearing behaviour, which are related to the condition of athletes, behavior of clothing, and their interaction with the performing athlete, etc.;
- The 5Ps Core properties layer further depicts the dynamic interactions between athlete, clothing system, and their integrative action towards performance and user comfort. It should be noted that two interactions occupy a single sector of the 5Ps in Figure 2, i.e. Psychophysiological and Physiological psychology. Both of these interactions depict the mind-body interactions and in this paper are regarded as one of the 5Ps;
- The outer layer depicts the related sports condition and environment (e.g. life profile, immediate body space, competition environment, and competition culture, etc);
- The subjective and objective evaluation methods that are correspondingly applied in analysis of 5Ps properties to determine comfort perception as shown in Figure 2. This layer illustrates that a complete evaluation of optimized performance and comfort must take into account both subjective and objective evaluation and these are often interconnected as in the psychophysical and psychophysiological sectors;
- Optimizing 5Ps properties and factors of multiple layers to achieve optimized performance and user comfort is the essential target of the proposed contextual model.

The developed model comprehensively reflects multiple mechanisms, multiple states, and multiple properties influencing an athlete's performance and wearing comfort. Rational consideration and integrative engineered design based on the 5Ps contextual model will help to optimize the functions, performance, and comfort of compression athletic wear and other related sports textiles.

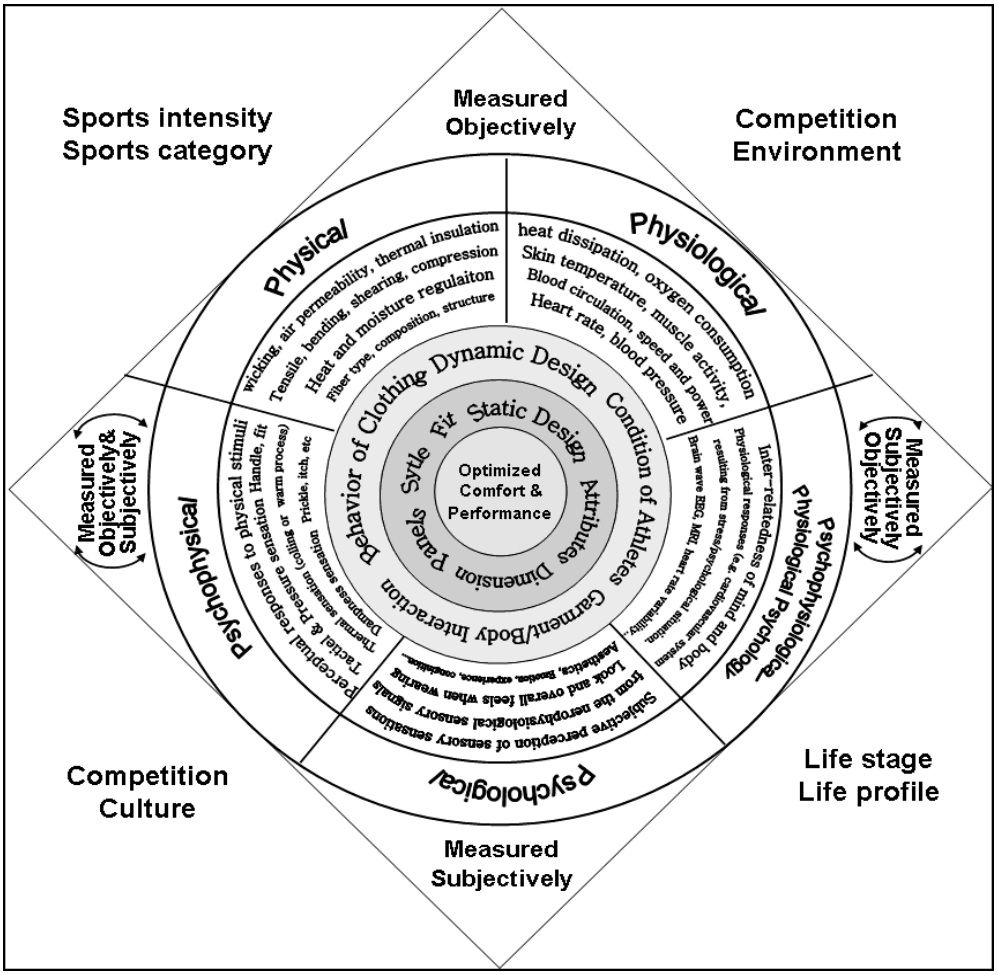

Figure 2 A 5Ps contextual model for optimized performance and comfort.

3. 5Ps Properties Related to Compression Athletic Wear

Compression athletic wear (CAW) are elastic, body-molded garments with engineered compression profiles that can be worn as upper-, lower-, or full-body pieces. They allow the exhibition of the natural curves of the form acting as a "second skin", so they are also called "Skinsuits". In today's competitive sporting environment, the application of CAW not only provide protection from injury from training and competition, but also as a means to signal and reflect athlete's personal characteristics, regional cultural, and fashion trends. The 5Ps properties, sensations, and interactions closely relate to the clothing-body-environment system, in that they are relatively independent of each other but also cooperatively impact and decide the ultimate user's performance and comfort. Understanding the individual "P" property is essential for integrative optimization of CAW.

3.1. Physiological Properties

Sports and exercise allow the athlete's body to face with tremendous demands that lead to many physiological changes. For instance, the energy expenditure in static position (sleep, sitting and standing) is about 1.2-1.8 kcal/min, while in the running and swimming, it is up to 14-20 kcal/min [8]. The heart rate increases from about 60 beats/min with standing to 180 beats/min or more with a fast-paced run. The sex, physical status, and training quality also variates sports physiological responses. The male expends more energy by about 20 % than the female during running [10]. The average maximal oxygen consumption (VO_2) of an untrained male in his mid 30s is about 40-45 ml/min/kg, while a champion male master runner age 50 will probably have a value of over 60 ml/min/kg, even an Olympic champion 10,000-meter runner will be up to over 80 ml/min/kg [11]. Intensive exercise commonly results in delayed-onset muscle soreness (DOMS), which negatively influences force-generating capacity of

muscle and recovery. In addition, different exercises and competition environments (e.g. air temperature, humidity, air velocity, amount of thermal radiation, etc.) also significantly affect sports status and performance of athlete. Heat cramps, heat exhaustion, heat stroke, wind-chill, shiver, and hypothermia are the common disorders when exercising in the hot and cold conditions.

The ability of a human to defend, regulate, and adjust the physiological variation under different situations tends to be limited. Engineered clothing systems, as a smart barrier, is one of the most important approaches to assist and protect the athlete's body against the external environment and to adjust the thermal exchange and humidity control between the body and its surroundings. Therefore, the positive impact of clothing system on physiological property is critically important to attain physiological comfort and psycho-physiological well-being of user.

Compression garments has been demonstrated to improve the venous function and blood circulation in many studies over the world during the last decade [12-15]. Berry and McMurray conducted initial exercise-related research on compression garments, finding a decrease in post exercise venous lactate concentrations and lower blood lactate concentration following maximal exercise when graduated compression stockings were worn [16]. Recently, advanced compression athletic wear has been developed by Speedo (Fastskin FS-Pro), Skins, Under Amour, Nike, Adidas, Champion, CW-X, etc., which has been commercially applied in training and competition to aid improving physiological performance during sports and after exercise to speed recovery. Experimental researches have demonstrated the benefits of compression athletic wear towards physiological performances and comfort as follows [13, 17-23].

- Reduced post-exercise trauma and lactic acid buildup
- Reduced perceived muscle soreness and oscillation
- Promoted recovery of force production
- Enhanced repetitive jump power
- Improved proprioception and core stability
- Increased oxygen delivery and minimize DOMS
- Regulated core temperature and keep user dry
- Enhanced circulation by promoting venous return

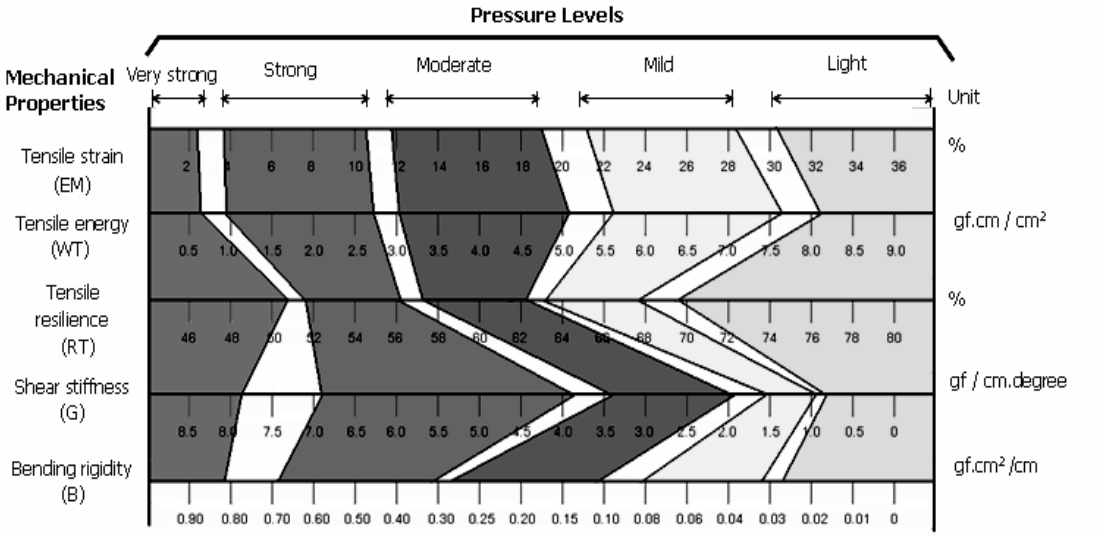

Figure 3 A plot of quantitative relationships between pressure levels for compression hose.

However, no benefit was found when wearing CAW for repeat-sprint or throwing performance. The clinical trial conducted by Berry *et al.* indicated that the use of elastic tights would not significantly affect post-exercise response or circulating lactate levels [24]. The influence of compression athletic wear on sprinting speed remains controversial [25]. Therefore, the effectiveness of CAW on sports performance and physiological parameters requires ongoing investigation.

3.2. Physical Properties

To achieve the above functionality, superior tactility, stretchability and thermal-moisture regulation are the critical physical properties for optimizing comfort performance of CAW. Elastic fibres and fabric provide controlled stretch and recovery characteristics that enhance easy comfort, freedom of movement and shape retention, and also provide the necessary condition to realize compression and

anatomic fit for CAW. Most of the current commercially available CAW adopted fabrics mixing spandex with nylon, polyester, and cotton, etc., such as Champion® Double dry men's compression T shirt with 88% polyester and 12 % spandex, Under Armour men's compression long sleeve with 93% PolyArmour™ and 7% spandex, Nike Women's Dri-Fit Compression Short with 96% Nylon and 4% Spandex, etc. To achieve wearing comfort in different seasons and environments, Coldgear® and Heatgear® of CAW series have been developed by Under Armour. Coolmax ® and Lycra ® Power™ technology further optimize compression and thermal-moisture comfort through providing powerful support with no restriction of movement (the stretch is even up to 210 %), maximum wicking capabilities and thermoregulation to support muscle and keep the body dry and cool, which has been applied in the performance compression tops and shorts developed by Lontex Corporation [26].

Most of the compression clothing for athletes used is designed as light or mild pressure levels with one layer, e.g. Sport Skins Classic full-leg tights (Skins™, Campbelltown, NSW) exerting average pressures of 9.1, 14.8, 17.6 and 19.3 mmHg along the posterior gluteus, medial vastus lateralis, medial gastrocnemius to medial ankle [11]. Compression profiles of clothing are significantly influenced by the mechanical properties of their fabrics [27-28].

Based on our previous study, Figure 3 illustrates the quantified relationships between pressure magnitudes and corresponding mechanical indices of compression hosiery by using Kawabata Standard Evaluation system [29]. It indicates that a reasonable combination of multiple fabric physical properties is of critical importance to attain an optimized pressure performance of compression garments.

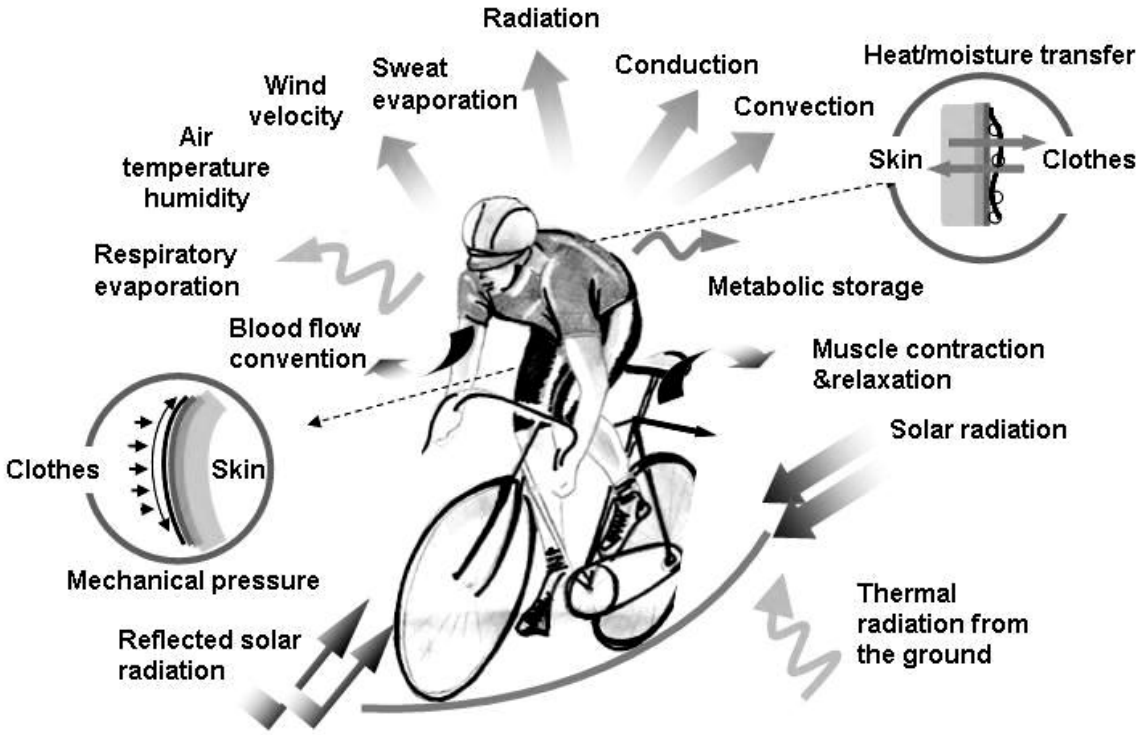

Figure 4 Complex interactions among multiple mechanisms and environment.

Intensive exercise generates an amount of liquid sweat staying on the skin surface. Some of the sweat spreads on the inner surface of fabric, which is next to the skin, then transfers from inner side to the outer surface and further evaporates into the environment; some of the sweat accumulates in the fabric or remains on the skin surface. Superfluous heating and moisture between closely contacted skin and athletic wear would negatively influence sports performance, and even threaten health. Therefore, air permeability, moisture absorption, wicking capability, thermal insulation are critical physical properties of CAW fabric, which are largely determined by fiber type, fiber cross-section, fiber size, fabric weight and thickness, knitting construction and structure, chemical and mechanical finish treatment, etc.

Furthermore, the functional construction design taking static and dynamic sports needs into account contribute to improve physical properties of CAW for performance and comfort, such as panels design, stabilizing web design, stitch selection, body fit, lightweight, and also absence of unpleasant odor, etc.

3.3. Psychological Properties

The psychological comfort is a judgment process by which the brain forms a subjective perception of sensory sensations from the neurophysiologic sensory signals and then formulates subjective overall perception and preferences by evaluating and weighing various sensory perceptions against past experiences and internal desires [30]. The psychological property of comfort is influenced by many factors, such as physical stimulation and environment, emotion, cognition, social, cultural surroundings and state of being, etc. While for the immediate body space, the psychological variations induced by physical stimulations, and the physiological responses to physical stimulations between athlete body and clothing, as well as physiological responses driven by psychological variations, more directly influence overall wearing comfort. It emphasizes the user's look and feeling when wearing CAW. Therefore, psychophysical and psychophysiological properties are regarded as the other two important considerations in the 5Ps model for optimizing user performance and comfort of athletic wear.

3.4. Psychophysical & Psychophysiological Properties

Psychophysical property deals with the relationships between physical stimuli and their subjective correlates or percepts. During the sports activities, the dynamic interaction between compression athletic wear and human body stimulates and triggers different receptors, e.g. mechanoreceptors, thermoreceptors, nociceptors, and photoreceptors, thus generating different senses such as touch (*smoothness*, *roughness*, *softness* and *stiffness*), thermal/wet (*cold* and *warm*, *dampness*, *breathability*), pain (*prickliness* and *itchiness*), and visual (*aesthetic comfort*). Skin is extremely sensitive to mechanical stimuli, and its displacement less than 0.001 mm can result in a sensation of pressure or touch [31]. The clothing pressure in the range of 30-45 mmHg was found to produce discomfort feeling [14].

The dimension of CAW is normally less than that of the user's body by 15-20 %. Therefore, the fabric surface properties and pressure magnitudes of CAW largely determine user's tactile and pressure sensation. Humans are homoeothermic, which keeps nearly constant internal body temperature ranging from 36.1 ℃ and 37.8 ℃. Garments worn in hot and humid environments can potentially alter the body's ability to achieve a state of thermo physiological and sensorial comfort. Thermal and dampness sensations are closely influenced by air permeability, wicking properties, wettability, etc.

Psychophysiology is the branch of psychology that is concerned with the physiological bases of psychological processes. For instance, it studies how exposure to a stressful situation will produce a result in the cardiovascular system (e.g. heart rate HR), vasodilation/vasoconstriction, myocardial contractility, or stroke volume, which is commonly evaluated by using objective methods, e.g. measures of brain activity, brain waves (electroencephalography, EEG), FMRI (functional magnetic resonance imaging), cardiovascular measures (HR, Heart rate variability), muscle activity (electromyography, EMG), etc. [30]. Therefore, Psychophysiological properties provide us a more rational and reliable reference to determine the psychological and physiological comfort status of user.

Many sports items are taken outdoors, such as track and field, mountain biking, rowing, soccer, and marathon, etc., and also Summer Olympic Games are normally held in August. High air temperatures, radiant heat sources, high humidity, and strenuous physical activities have a high potential for generating heat stress (Figure 4). Superior thermal and moisture regulation of compression athletic wear is an important approach to prevent athlete's heat stress thus achieving competitive performance. Manabu *et al* conducted a wear trails to study the effect of clothing compression on the respiratory and thermoregulatory responses during dynamic exercise. Oxygen consumption (VO2), Heart Rate (HR), mean blood pressure (MBP), rectal and skin temperatures (Tre and Tsk), and sweating rate (SR) were measured. It indicated that pressure around 45 mmHg
around thighs could elicit muscle chemoreflex due to accumulation of metabolites in exercising muscles.

Exercise training with pressure to active muscles can improve aerobics performance more effectively than without pressure [32]. Li *et al.* tested the sweat loss during subject walking on a treadmill at 5.6 km/h for 40 minutes when wearing wool and polyester garments at 28 ℃ and 30% relatively humidity (RH). No difference in sweat loss of upper body during exercise was found between wool and polyester garments. While subjects reported feeling less clammy and warmer when wearing wool than when wearing polyester during the period between 10 and 30 minutes [33]. These psychophysical and psychophysiological studies provide us a reference for optimizing functional performance of athletic wear and also allow us to have further understanding to learn clothing-body-environment system.

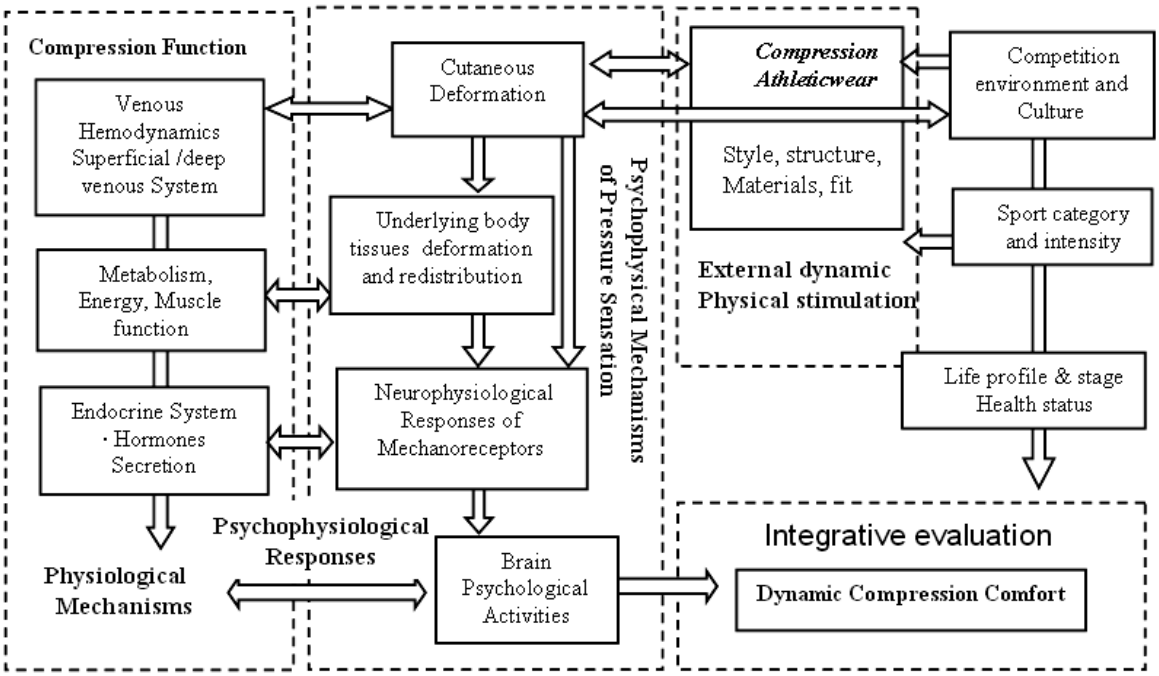

Figure 5 Interactions of 5Ps property related to compression comfort of user towards to CAW.

4. Optimized Design of CAW Based on 5Ps Model

During dynamic sports, the 5P properties interactively influence user comfort. Figure 5 takes an example to outline the interrelations among 5Ps properties related to dynamic compression comfort of athletic wear. The major consideration in performance design of CAW includes:

- Physical-mechanical properties for tactile/pressure functional performance;
- Physical thermal and moisture regulation;
- Bionic fabric innovation for sports performance;
- Fit and panels design for kinetic comfort;
- Technical design in assembly;
- Aesthetics and style design for expression (personality, culture, etc);
- Biomechanical construction design for targeted regions;
- Enhanced aerodynamic and hydrodynamic performance.

Sports companies have attempted to design and develop advanced functional compression athletic wear to improve comfort and sports performance through optimizing 5Ps properties. For example, Lycra ® and Coolmax® of differing contents and composition with natural and synthetic fibers are used in CAW to balance pressure perception and thermo-physiology comfort, such as Nike® Pro compression apparel. Mesh ventilation materials are used in targeted zones of CAW (i.e. underarm, front chest, shoulder blade, waist, etc.) to regulate skin temperature and perspiration for skin cool and dry. Speedo took inspiration from biological skin characteristics of various marine animals, such as Shark, to design innovative swimsuit to reduce surface resistance by up to 15%. In 2008, Speedo launched the LZR Racer suit made of light weight woven fabric with polyurethane panels to reduce drag. To date, 38 world records have been broken in the new LZR Racer suit [34].

To reduce the muscle oscillation and prevent injury, CW-X's patented Conditioning Web™ applied taping system to help the muscles and ligaments band together to stabilize the knee joint and diminish the opportunity for injury based on the kinetic skeletal muscle structure. Over 40 years of research on 35,000 female bodies at the Wacoal Human Science research center in Japan led to CW-X's soft support web™ bra that applies a quick-drying elastic base strap sitting comfortably around the rib cage, which works in tandem with the inner cup support web and shoulder straps to support the wearer during different levels of athletic activity. The gluteus medius are considered in every running injury. The strength and function of this muscle is probably the most important active component in the achievement of a biomechanically efficient running technique [35]. Adidas TechFit Powerweb long tight design incorporates TPU banding with compression properties at gluteus muscle to enhance athletic

posture, movement and overall athletic power.

The ability to maintain adequate circulation plays an important part in the recovery phase by enhancing the elimination of built-up lactic acid. Engineered compression has been applied to exert a controlled external pressure over specific body parts. During sports, the recoil force by the elastic fabric with limited stretch triggers an acceleration of venous of blood flow, thus enhancing blood flow and venous return, increasing oxygen delivery to working muscles and more rapidly eliminating lactic acid and waste. SKINS^{TM} claim that their developed CAW helps reduce the build-up of lactic acid immediately after periods of sustained exercise (2hrs and 15 mins up to 37 % reduction), and allows for more rapid return to normal levels (up to 38 % at 20 minutes).

Functional Panels design has been used in bike shorts to contour the garment to fit the body in the cycling position. In addition, the improved assembly technology has been applied to minimize dragging, chafing and irritation, to attain comfort tactile and touch perception in dynamic motion, such as the use of flatlock stitching and welding in seam treatment.

In addition to the inter-relations between 5Ps properties, the optimized user comfort are also determined by athlete's somatotypes, height, weight, percent body fat, life stage, cardiorespiratory power and efficiency, etc., and dynamically influenced by environment, cultural significance and fashion identity (i.e. colour, pattern, proportion, unity, etc).

Table 1 Olympic Sports, Athletes, and Athletic Wear

Olympic Sport	***Athletic Category***	***Physical Demands***	***Athletic wear***
Athletics (Track and Field)	Running, Jumping, Field Events	Speed, endurance, power	Form Fitted/Loose
Badminton	Racquet Sport	Aerobic stamina, agility, strength, speed and precision	Semi-form fitted
Baseball	Bat-and-ball	Strength, speed, precision/power	Form-fitted
Basketball	Team sport, indoor or outdoor	Agility, speed, precision	Loose
Boxing	Combat sport	Strength, speed, defense	Loose
Canoeing	Kayak, straight racing	Endurance, speed	Form fitted
Cycling	Bicycle ridding	Endurance, power, speed	Form fitted
Equestrian	A horseback rider	Precision, skill	Semi-form fitted
Fencing	Competitive swordsmanship	Speed, precision, skill	Semi-form fitted
Football (Soccer)	Team sport	Speed, stamina, skill, precision	Semi-form fitted
Gymnastics	Competitive physical exercise	Agility, coordination, stabilization	Form fitted
Judo	Martial art and combat sport	Skill, strength, power	Loose
Rowing	Competitive water sport	Endurance, skill	Form-fitted
Table Tennis	Racquet sport	Skill, speed, precision	Semi-form fitted
Tennis	Racquet sport	Endurance, skill, speed	Semi-form fitted
Wrestling	Martial arts	Strength, stabilization, skill	Loose
Triathlon	Multi-sport endurance event	Endurance, power, speed	Form-fitted
Weight lifting	Weight training	A combination of power (strength and speed), technique, flexibility and consistency.	Form-fitted

5. Discussion and Conclusion

In recent years, the promotion and desire for healthy lifestyle and environmental friendship have become a trend directing functional design and eco-materials innovation of athletic wear. The athletic wear provides athlete's a dynamic near environment in sports. The selection of athleticwear, to a great extent, is dependent on sports items, physical requirements and environment. Table 1 lists the sports of the

Olympic events and their corresponding physical demands and apparel status.

The functional performances of existing advanced compression athletic wear have been demonstrated in experimental studies and competition achievements. However, a number of issues still need further investigation. For instance, the sports category and intensity that influences sweating, core and skin temperature, might place different fabrics and mesh panels to provide most efficient thermal/moisture regulation and prevent heat stress. And, how to apply different compression to fit different athlete's bodies to improve sports performance and comfort?

The subjective and objective measurement and evaluation of 5Ps property will contribute to identify their individual quality and help us to integrate and optimize 5Ps to achieve most competitive comfort and satisfaction. Direct and indirect approaches can be used in subjective and objective evaluation. For instance, pressure monitoring system can be used to test compression profiles [27,36,37]. Series of ASTM, AATCC, and ISO standardized approaches can be applied to directly test physical-mechanical properties of materials. Physiological parameters as markers can be selected to test related body system and physiological mechanisms, e.g. heart rate and blood pressure are usually as the physiological marker for autonomic nervous system, and the urinary excretion of hormone cortisol for reflecting stressful status, etc. Wear trials can help us analyze the psychophysical property and user's psychological comfort; electroencephalography (EEG), electromyography (EMG) and cardiovascular measures can be used to determine psychophysiological property when user wearing CAW.

The Olympic Games have been served as laboratories for technological developments in fabrics and sports apparel design as well as a showcase for functional performance and fashions. The athletic wear worn by professional athletes undoubtedly influences the clothing worn by amateurs, and even non-sports apparel design. Today's athletic wear not only technically and physically assist sport performance, but also display the body, reveal personality, spread regional culture and sports spirit. The developed 5Ps contextual model presents the interacting factors and their inter-relations deciding functional performance of athletic wear and user comfort, thus providing a reference in optimization and application of compression athletic wear and other related sports devices.

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